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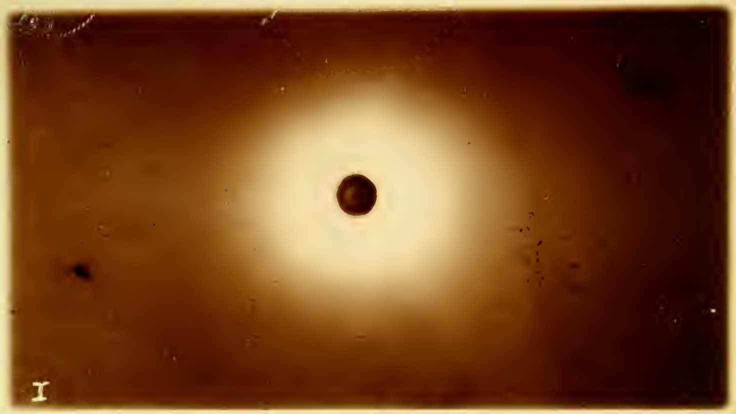

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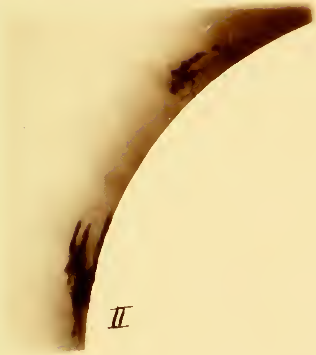

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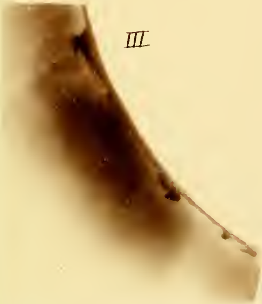

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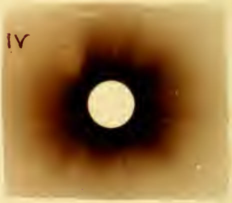

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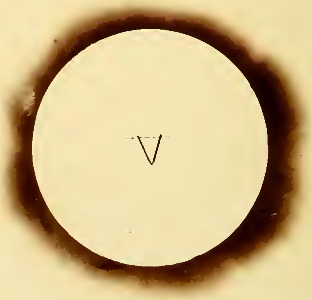

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CONTRIBUTIONS FROM THE LICK OBSERVATORY NO. 4.

REPORT

ON THE

TOTAL ECLIPSE OF THE SUN,

OBSERVED AT

MINA BRONCES, CHILE,

ON

APRIL 16, 1893.

BY

J. M. SCHAEBERLE,
Astronomer in the Lick Observatory.

Printed by authority of the Regents of the University of California.

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The Expedition to observe the Total Eclipse of the Sun of April 16, 1893, was sent from the Observatory at the cost of Mrs. Phebe Hearst, a friend of the University of California.

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ERRATA.

On page 10, insert the word "central" between the second and third words of the tenth line from the bottom of the page.

On pages 17 and 31, for "Wolff" read "Woolfe."

On page 31, for "Williamson, Guthrie & Co." read "Williamson, Balfour & Co."

TOTAL SOLAR ECLIPSE OF APRIL 16, 1893.

By J. M. Schaeberle.

Preliminary Remarks.

The peculiarly favorable location of the track of the moon's shadow during the total eclipse of April 16, 1893, rendered it extremely desirable to occupy various points along this line as observing stations. The interval of time between the extreme positions which could be advantageously occupied being of several hours' duration, it might be possible to detect with certainty changes in the form of the corona during this interval.

It was decided that if the Lick Observatory could secure the necessary funds to send out an expedition, some point in the interior of Chile should be selected for observing the eclipse, as the atmospheric conditions throughout the Desert of Atacama were known to be excellent. Mrs. Phebe Hearst, a friend of the Observatory, had provided in 1892 a fund which was to be used in aid of scientific undertakings at the Observatory. On the recommendation of the Director of the Observatory, and with her cordial sanction, the sum of $1,000 from the Hearst Fund was set aside for the expenses of the expedition in the field. The Regents of the University authorized the use of the necessary instruments.

Preparations for the eclipse were commenced in the fall of 1892. I was particularly desirous of photographing certain phenomena on a very much larger scale than had ever before been done, for it seemed that only in this way could certain doubtful points be decided, and marked advantages be gained over the usual results.

The finer details of the corona are necessarily lost in photographs taken on a small scale. Special attention was therefore first given to the designing of an instrument which should be capable of furnishing satisfactory results on a very large scale when used under the peculiar conditions presumably prevailing in the interior of Chile.

The excellent Clark objective of 5 inches aperture and 40 feet focal length, specially corrected for the photographic rays, seemed to be the lens most suitable for this purpose. It forms part of the horizontal photo-heliograph of the Lick Observatory. In deciding upon the method of mounting it was never for a moment thought practicable to use the ordinary equatorial form in which the tube is suspended near the middle of its length, on account of the great expense attending the completion of such a plan, and for the still more serious reason of its instability in an exposed position at a high altitude, where the atmospheric movements are often quite strong. Any advantage due to the large scale given by a telescope 40 feet long will, in a great measure, be lost unless great stability of the image on the photographic plate is secured.

It was not deemed advisable to use the horizontal form of telescope in connection with a plane mirror, as the best results which could be given by the lens alone could not be obtained if an intermediate reflecting surface were to be introduced, to say nothing of the effects produced in long exposures by a rotation of the image in position-angle with a change in the hour-angle of the sun.

Only one plan was considered feasible, and that was to place the object-glass on one fixed pier, and to mount the movable photographic plate on another, both piers to be wholly free from contact with the great tube. The motion of the slide carrying the photographic plate was to be so regulated by means of inclined guides and a clock-work, as to give it the same velocity and direction as the sun's focal image on the day of the eclipse.

To test this plan, as well as to determine the position of the photographic focus, the lens was mounted in the slit of the meridian circle room. A series of exposures was then made, giving star trails at various distances from the true focal plane. Another series of exposures made with the photographic plates inclined 45° to the optical axis, gave trails which furnished still more accurate means of determining the best focus. From observations made on several different nights the most satisfactory position of the focal plane was found to be 40 feet 1.2 inches from the nearest surface of the lens. This was adopted as the focal length.

To test the character of the results obtained in making long exposures, an iron frame-work in the form of a quadrilateral was placed in the focal plane. The parallel sides of this frame served as guides for a triangular slide which carried the photographic plates. Three carefully made wheels, whose axes were fastened to the triangular slide, served to carry the latter. The two lower wheels had knife edges working in a V groove cut in the upper surface of the lower guide; the third wheel simply rolled on the planed surface of the upper guide.

The lateral motion (diurnal) was given to the plate by the unwinding of a strong, flexible wire wound around a drum mounted on the clock's winding axis. The size of this drum was determined by computation, and the final adjustment of the velocity was then made by shifting the balls of the centrifugal governor. The motive power was a weight at the extremity of a cord hung over a pulley and attached to the slide. At the eclipse station this weight was dispensed with, as the slide's weight and the inclination of the line of motion were sufficient to furnish the motive power for running the clock. (See Plate V.)

Besides photographing star images, a series of excellent moon photographs were obtained with exposures varying from 1 second up to 32 seconds. These preliminary experiments clearly demonstrated the practicability of the method for eclipse work, in which all the photographs to be taken must be exposed during an interval of only a few minutes of time. A want of success in obtaining the best possible results cannot be attributed to a faulty principle in the method. To make sure, however, that everything should be in perfect working order on my arrival in Chile, it was decided to set up the 40-foot telescope on Mount Hamilton.

In designing and constructing the parts it was, of course, necessary to know beforehand the approximate geographical position of the eclipse station, in order to obtain the proper angle of elevation of the inclined portion of the tube, and the form of the wooden pier for holding the photographic slide. For this purpose a point on the central line of the moon's shadow-path, and about 50 miles from the coast of Chile, was used as a basis for preliminary computation.

The tube of this telescope was made of canvas, painted black both inside and outside. In order to avoid any considerable reflection of light from the sides of the tube the dimensions were made very large, being 2 feet by 2 feet in cross-section at the objective end, and expanding to 4 feet by 4 feet near the lower end of the inclined tube, where it terminated in a cubical room whose sides were 6 feet. Small iron rings sewed to the longitudinal edges of the tube at intervals of a few feet served to secure the canvas to an encircling frame-work made of wooden uprights, 3 by 3 inches and 6 feet long, placed at intervals of 6 feet from each other. The frame was braced longitudinally and crosswise by strips 1 by 3 inches cross-section. This telescope was temporarily erected on a slope of Mount Hamilton east of the Lick Observatory, and successfully withstood the winter storms for several weeks, when it was taken apart and securely packed for shipment to South America.

In addition to the 40-foot telescope, four other photographic instruments were taken to Chile. These were:

(1) The 6-inch CLARK equatorial of 6 feet focal length, belonging to the Lick Observatory.

(2) A 6-inch DALLMEYER portrait lens, loaned to the expedition by Hon. WM. M. PIERSON.

(3) A 5x7 camera.

(4) A 4x5 camera.

The 6-inch equatorial has been described in previous publications of the Lick Observatory (see Lick Observatory reports on the eclipses of January and December, 1889), to which the reader is referred for particulars as to mounting, etc. It was used in essentially the same way as at Cayenne.

Mr. PIERSON'S Dallmeyer lens was screwed into one end of a rectangular box, having such dimensions that an 8x10 plate could be exposed in the focus. As this instrument was not provided with a separate mounting, and as I contemplated using it for several different lines of investigation requiring long exposures (and consequently a uniform diurnal motion), the box was so built that it could easily and securely be strapped to the CLARK equatorial, and the latter instrument used as a guiding telescope. Just before the date of the eclipse, this camera was to be dismounted and placed upon a separate pier, and then used for photographing the sun's surroundings during the total phase.

The 5 x 7 and the 4 x 5 cameras were also to be used for this purpose, with stationary mounting.

In addition to the optical outfit a very complete supply of photographic material was included. In fact, nothing was left wanting to carry on the photographic work at the eclipse station. When it is considered that plates of the size of 18 x 22 inches were handled and completely finished at Mina Bronces, one may obtain some idea of the amount of extra apparatus required to be taken up in the Andes.

A chronometer and sextant, to be used for finding latitude and longitude, formed a very essential part of the outfit.

It was first intended to occupy a station near Vallenar, which Professor OBRECHT of the Santiago Observatory had selected, and for which he had determined the geographical position, and which was eventually occupied by the Harvard College Observatory party under Professor W. H. PICKERING. Later on, however, I learned through some published information given by Mr. JOHN KING, British Consul at Carrizal Bajo, that by going farther into the interior much higher ground and better atmospheric conditions could be reached, the only unknown elements being the geographical locations.

I finally changed my original plan of going to Vallenar, and, despite the increased number of difficulties to be overcome, decided to locate, by astronomical observations after reaching Chile, a station at a great altitude on the central line of the eclipse. This change of plan necessitated an early start.

THE VOYAGE TO CHILE.

On January 16, 1893, the boxes—thirteen in all—containing the equipment were taken down the mountain, shipped to San Francisco, and put on board of the Pacific Mail Steamship Company's boat "The City of Sydney," Captain FRIEL, bound for Panama and intermediate ports.

We left San Francisco on January 25, and arrived in Panama, after a very pleasant voyage, February 10. At the stopping-places there was always the opportunity of going ashore with a camera for taking instantaneous views, and thus were secured many interesting and instructive photographs of a decidedly non-astronomical character. These side trips serve to make the time pass very rapidly, and the traveler feels that he is all the while storing up useful information. Between San Francisco and Panama we stopped at the following ports: San Diego, Cal.; Mazatlan, San Blas, Manzanillo, Acapulco, Champerico, all in Mexico; San José, Guatemala; La Libertad, San Salvador. At San José de Guatemala a party of us, including Captain Friel, went to the town of Esquintla, about 30 miles inland, connected with the port by a railroad. Two imposing extinct volcanic cones, *Agua* and *Fuego* by name, and visible as conspicuous objects from the steamer, appear to be almost at the outskirts of the town. The vegetation is superfluously abundant and the colors irresistibly tempting, as the writer can testify, for after he had gathered a bouquet of the most gorgeous flowers, and was in the act of hastily grasping a particularly beautiful plant as the train was starting, a loud cry from a native warned him not to touch the weed—too late, however; almost instantly my hand was covered with ants, apparently thousands in number, and all stinging like bees. The color which had been so much admired was produced by these very insects, which literally covered the whole surface of the plant. Of the lively time had in getting rid of the pests the reader can perhaps form a mental picture.

In the harbor of San José (Guatemala) passengers have the rare treat of watching the motions of the sharks which in great numbers surround the vessels, in search of food. As an interesting incident, it is worth mentioning that our first mate, Mr. Brown, wounded one of these creatures with a pistol shot; almost instantly the monster was pounced upon and devoured by the others.

During the night of February 10–11 the red glare of an active volcano was a strangely interesting object for several hours as we were steaming southward. The light was periodically variable; the length of time from one outburst to the next following was only a few minutes.

At Champerico we were unexpectedly detained a whole day taking in coffee for Hamburg; as this delay was not made good later on, we arrived in Panama Bay just in time to see the English line steamer leaving on her way to Valparaiso. The next steamer (Chile line) was to sail a week later, and I learned that, while my ticket was good on both lines, the officials at San

Francisco had billed the freight in such a way that it could only be carried on an English steamer, the next boat south being due in two weeks. Rather than wait a fortnight in Panama, I canceled the bill of lading and reshipped the goods from there to Carrizal Bajo by the Chile line.

I left Panama on February 18 on the steamer "Mapoche," Captain Roberts, and two days later the snow-covered Andes were first sighted. On February 22 we anchored in the middle of the Guayas River, opposite the city of Guayaquil, the principal port of Ecuador, situated about 90 miles up the river.

Our steamer was the first boat of either line to call at this port in several months, the city having been quarantined on account of a yellow fever epidemic. What surprises the traveler most is that with the existing want of proper sanitary measures such a place should ever get free from a plague.

Our first Peruvian port, Tumbez, was made on February 23; the following day we anchored at Payta, on the 25th at Eden, at Salaverry on the 26th, and finally, after *feeling* our way in a dense fog, with islands to be avoided, for nearly a whole day, we reached Callao harbor on the evening of February 27.

During the entire voyage down the coast, the steamer, with only a few exceptions, remains within sight of land. After leaving California, Callao is the only port on the American side of the Pacific where the larger vessels can go up to the dock. As we were to remain here for several days, an excellent opportunity was presented of making a short visit to the famous city of Lima.

Whatever energy and glory this historic place may have possessed in the past, the visitor's attention is everywhere attracted to signs of shiftlessness and decay. Since the invasion of the country by the Chileans—evidences of whose devastations are still to be seen on every hand—the people seem to have lost heart. The same want of energy was made apparent at the other Peruvian ports visited, viz.: Pisco, Chala, Mollendo, and Ilo.

Our first Chilean port, Arica, was reached on March 5, and I was at once struck with the different character of the town and the people. The whole place is comparatively neat and pretty; the inhabitants seem to have more of that vim and push so characteristic of the dwellers of the north temperate zone. At the southern extremity of the town a rocky bluff rises abruptly from the water's edge to a height of several hundred feet. It was from the top of this rock that the victorious Chileans in combat hurled the Peruvians to their watery graves below. Captain Roberts was in this harbor at the time and witnessed the tragic scene.

The next day we arrived at the large, important commercial town of Iquique, famous for its nitrate works. Here, for the first time, the northerner hands his street-car fare to female conductors. Women are employed in this capacity on nearly all the tramway lines of Chile. As in Panama and other South American cities, the pedestrian is everywhere entreated by the young and the old of both sexes to buy Government lottery tickets. This miserable and pernicious business serves to raise revenue for special purposes. Gambling of all kinds appears to be carried on without secrecy. In the streets it is no uncommon sight to see a crowd of youngsters pitching 10 centavo pieces in games of chance.

Antafogosta, Taltal, Caldera, and finally Carrizal Bajo, where I arrived on March 9, were successively visited. At Taltal the Chilean boat "Itata" (in which our own Government was at one time so much interested) lay at anchor.

From Caldera I telegraphed Mr. King, and on arriving at Carrizal Bajo I was most cordially greeted by this gentleman. The instruments were at once taken ashore and placed in the custom-house. On the following morning numerous telegrams, from various State officials, were received, authorizing the local officers to give me any aid in their power.

The town of Carrizal Bajo is probably the dreariest of the desolate-looking small ports at which the steamers stop. As seen from the ship, there is only one green spot, due to a clump of trees, in the whole place, and, as it afterwards turned out, this particular location is the home of Mr. King, British Consul.

SELECTION OF THE ECLIPSE STATION.

As the state of the weather did not allow a determination of the local time, and as I did not wish to delay going into the interior for another day, or possibly more, before the removal of the clouds and fog, the sidereal chronometer was started to indicate approximate Greenwich sidereal time. A mean solar time chronometer on board the bark "Iron Crag" was used for this purpose. Mr. KING was of the opinion that for the preliminary work the geographical positions of the two railroad terminals were sufficiently reliable.

On March 10 a special train for the interior was made up, consisting of an engine and tender, the Superintendent's private coach, a car with three riding horses, and another car containing feed for the animals.

It is proper to state here that through the kindness of my friend, Mr. ROBERT BRUCE, of the firm of BALFOUR, GUTHRIE & Co., of San Francisco, Mr. KING (Railroad Superintendent as well as Consul) had received oral instructions from Mr. HENDERSON, Vice-President of the railroad, to give whatever aid I required.

The road into the interior is all up grade, winding through valleys and cañons almost completely devoid of vegetation, except at the several stations along the line, where the artificial water supply is sufficiently abundant to permit of its being used for irrigating areas of less than an acre in extent. The only interior place of any importance is at Chañarcitos (see Plate II). Here are located extensive smelting works for reducing copper ore received direct from the numerous mines of the surrounding region. Before starting out I decided, from information given by Mr. KING, to go first to Carrisa Valley, beyond the northern terminal of the railroad, and which we expected to reach on horseback the following day. At about dusk we arrived at Yerba Buena, the terminal station.

An immediate provisional reduction of the sextant observations made the same evening showed that this place was about 20 miles from the central line, so that an attempt to secure a station in the Carrisa Valley would make it necessary to go much farther than at first supposed. The mountain Cerro Blanco (distant about 10 miles)—which was also under consideration as a possible station—was shown by these observations to be still farther from the central line. I now resolved to go to the southern terminus of the railroad, called Merceditas, which would certainly be nearer to the moon's shadow-path if the railroad surveys were approximately correct. The locomotive had been sent back to the port the previous evening, so that our return to the junction was made without the aid of an artificial motive power, gravity alone being used to propel the train. At Chañarcitos our special car was coupled to the regular bi-weekly train for Merceditas, where we arrived that same afternoon. Mr. King had previously visited this neighborhood, and had recommended one of the mountains to the south of the station as a suitable location for an eclipse observer. We went there on horseback, but long before our arrival I felt convinced that it would be unwise to occupy this mountain, for, in the first place, considerable expense would necessarily be incurred in repairing the steep and dangerous trail before the instruments could be taken over it with any degree of safety; secondly, there were no conveniences in the way of quarters or materials for construction, the nearest point for securing even the smallest wants being the station-house. After our return to the latter place, which lies in the bed of a dry cañon with steep slopes to the mountain sides, I found that, owing to the favorable azimuth of the general direction of the cañon, the local place in the sky that the eclipsed sun would occupy could be seen from a spot near the station-house, although the first contact would occur while the sun was still behind the mountains. It was repeatedly remarked both by Mr. King and the station-master that the fog, which nearly every morning filled the valleys and plains lower down, never reached Merceditas at that season of the year; my own experience at Mount Hamilton had, however, shown that the exceptional condition of the weather might occur at almost any moment. Only as a last resort would I have consented to occupy this cañon as an observing station. That night's provisional sextant observations and reductions made it evident that, instead of being close to the line of totality, we were still nearly 15 miles on the north side of this line.

The mining camp Mina Bronces, which was supposed to be too far south in latitude to make it desirable as a station, was said to be about 20 miles from the Merceditas by-road, and as it was in the direction of the central line, I resolved to occupy the place for one night at least, and determine its approximate position. Accordingly the following morning we started out on horseback, taking the cart-road in preference to a trail, as Mr. King had never been at Mina Bronces; the danger of getting on a wrong

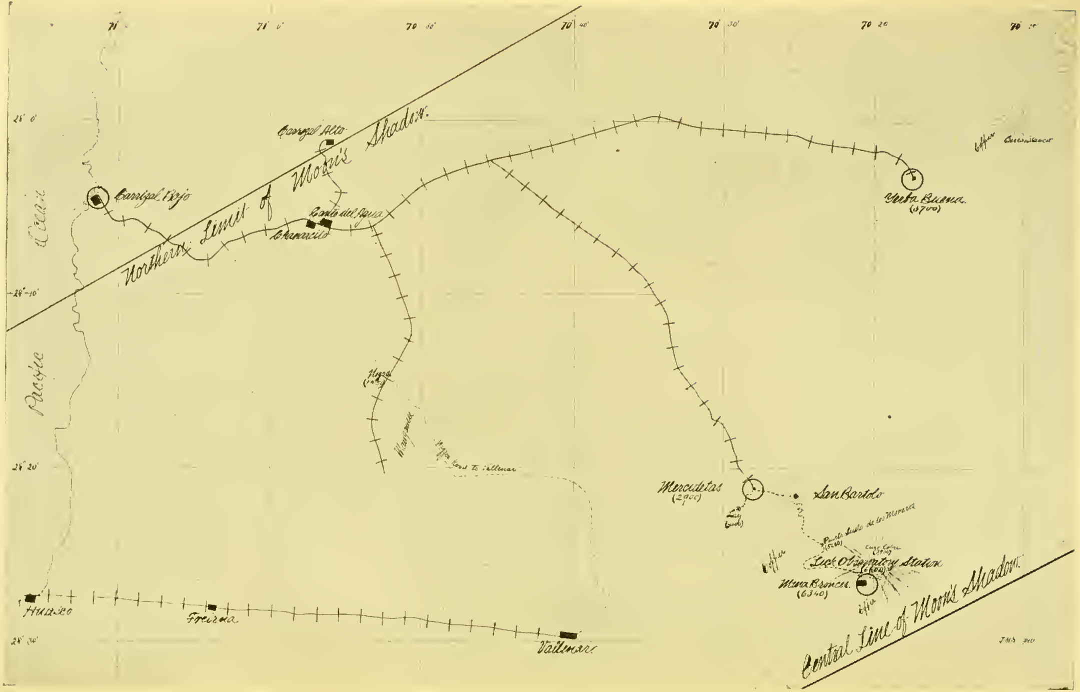

Plate II. Map of the Region near Eclipse Station.

trail is very great in this locality. Before leaving it was noticed that the fog was within less than half a mile of the station, completely filling the lower end of the valley.

After five hours' riding over a very rough and dusty mountain cart-road, Mina Bronces, the place destined to be used as the Lick Observatory eclipse station, was reached, and here we were most hospitably received by Captain Bray, an Englishman in charge of the mine. My aneroid indicated an altitude of 6,500 feet; Mr. King's instrument read 200 feet higher.

The preliminary observations and reductions made on the evening of our arrival gave results which, for the assumed longitude of Merceditas, were so close to the ones desired that it was somewhat uncertain whether the mine was north or south of the central line.

In going from Merceditas to Mina Bronces the road makes so many turns and crosses so many cañons and ridges that it is impossible to form in the ordinary way an estimate of the actual air-line distance and direction from the starting point. About half way, and almost exactly on a straight line joining the two places, the traveler crosses a ridge called by the miners "Porte Suella de los Mineros," where, at an altitude of 5,200 feet, the mine is first seen, and in the diametrically opposite direction some conspicuous landmarks close to Merceditas are also brought into view. With the aid of a convenient pocket instrument I found that the magnetic bearing of the mine from Merceditas was S. 62° E.

The mining camp is located near the head of one of the numerous cañons which radiate from Cerro Cobre on its west slope (see Plate III). This mountain, as viewed from the camp, cuts off at least 30° of the sky in altitude. On the south slope of this particular cañon steep trails lead to a rather level area 260 feet higher up, and distant less than half a mile from the camp. From this point it was found that vertically under the place which the sun would occupy during totality the view was unobstructed down to within 10° of the horizon. Aside from the fact that the first contact could now be observed, the presence of the mountain would be of real advantage during the total phase, as the greatest portion of the sky-glare, which would evidently be a maximum near the eastern horizon, would be cut off.

It was probable that the longitude of Merceditas as deduced from the railway surveys was fairly reliable, so that the position of Mina Bronces could not be much different from the value given by the first night's observations. I was, however, not fully satisfied with the character of the data obtained. The difference between the longitude of Merceditas and that of the mine depended upon the running of my watch, the chronometer having been left at the former station. Then again, some of the *experts* at the mine claimed that the coast was not more than 30 miles distant, while others claimed 80 miles as a fair estimate. All of my latitude determinations were, of course, certain to within a fractional part of a mile. Accordingly, I decided to go back to the coast and obtain an independent check upon the position of the mine. Captain Bray gave us directions for finding the trail back to Merceditas, and as Mr. Tirepegui, a mining engineer, who was to accompany us as far as Chañarcitos, had previously been over the trail, we felt quite confident of reaching the railroad in two and one half hours. Unfortunately, however, we left the cart-road by the wrong trail. After several hours' riding we became aware of our error, but rather than retrace our way, we agreed to trust to a general knowledge of the direction we wished to go. After five hours of traveling over cow-trails which nearly always ended at a natural spring, and just as we were on the point of turning back, San Bartolo (see map) suddenly came into view, many hundred feet almost directly below. To get lost in the Andes is a very serious matter, for nowhere does Mother Earth furnish food for the unprepared traveler. The habitations are few, and of the numerous trails ninety-nine out of a hundred are cattle-trails, which usually end at a spring of water.

Under ordinary circumstances we would have missed the train, but the conductor's orders were to wait for the Superintendent and party. We reached the port two hours late that same night. At one portion of the railroad the down grade is so slight that the conductor always allows the train to acquire great velocity in order to carry it over the nearly horizontal stretch. On this day, however, the wind was blowing up the valley with such force that the necessary headway could not be acquired; our engineless train came to a standstill, and the only way out of the difficulty was to put our shoulders to the cars and push them over the mile or more of track until reaching a grade sufficient to overcome the opposing force of the wind.

Before leaving Merceditas some solar observations for time were made, and that same night another set of results was obtained at Mr. KING's residence, near the railroad station in Carrizal Bajo. The following day, A. M. and P. M. observations were also secured. On March 14 I returned to the interior alone, the instruments having been sent on ahead. At Chañarcitos I first met Mr. WALKER, on his way to Mina Bronces to set up some machinery. Mr. BRAY had kindly sent saddle horses and a guide to Merceditas. A short series of observations on the sun were again made here before leaving for the mine.

As long as the transportation was by rail there was but little danger of the chronometer getting out of order, as it was carried in the hand whenever any serious jolting occurred, and frequent comparisons with the watch made it certain that, whatever slight change might result in the daily rate, no tripping was taking place. The ride to Mina Bronces was necessarily quite slow; the chronometer was carried in one hand, and what at the time appeared to be a rather spirited horse, managed with the other. One who has never tried to keep a chronometer from tripping under such circumstances can form no idea as to the nature of the sensations each unexpected motion of the beast produces. However, everything passed off in a most satisfactory manner. That same night observations were again made at Mina Bronces, and the reduction of them the following day fully confirmed the general correctness of the previous approximate position. The results of the observations at the several stations will be found farther on.

With respect to the transportation of the instruments, it required almost reckless determination to allow them to be taken over the long, rough mountain road; but the advantages of Mina Bronces as an eclipse station were of so superior a nature, in reference both to the abundant supply of water for photographic purposes and to the many conveniences for carrying on the preliminary work, that it seemed equally inexcusable not to make use of the opportunities this station afforded. I was very much relieved on opening the boxes to find that, aside from a liberal coating of dust and a general shaking up, nothing was broken or damaged.

A furnished bedroom in one of the main buildings, and in another building a large room for photographic work, were placed at my disposal.

For the eclipse station proper a number of places in the immediate neighborhood of the mine were examined, but none of them seemed to be quite as convenient of access as the one on the plateau 260 feet above the main building. As the officials offered the use of a riding horse, the daily trips over the trail, both by day and by night, would not be wearisome to the observer. Walking was good exercise, however, and often the horse was not used for days at a time.

Of the everyday life at Mina Bronces a volume of interesting matter might be written without exhausting the material which a six weeks' stay at the mine affords. It is, however, foreign to the object of the present publication to more than mention a few pertinent facts. All told there are about four hundred souls dwelling within the huts and the two long one-story buildings.

The standard of morals is rather low; much of this is of course due to the lack of education, and also to the very small wages; a miner receives nominally about $1 of Chile money per day, the value of which in gold coin was, in April, 1893, about 33 cents. Chile is, however, awakening to the necessity and advantage of having good free schools, so that now the schoolroom is to be found in every village throughout the State; the one at Mina Bronces has an excellent teacher, and the attendance is large.

Pay-day comes around once a month, on Saturday. The next day, Sunday, nearly all the miners are under the influence of a species of liquor called "chicha," and often by the following Monday many of the unfortunate ones are obliged to beg Captain Bray for an advance to live on until the next pay-day.

All food, for both man and beast, must be brought from a distance. Vegetables, alfalfa, and grain in limited quantities are grown in the neighboring watered valleys and brought to the mine on the backs of burros. Except in these watered valleys, the whole surface of the country is devoid of useful vegetation. In places on the mountain sides is still to be found a dry, withered-looking bush, which is being slowly but surely exterm-

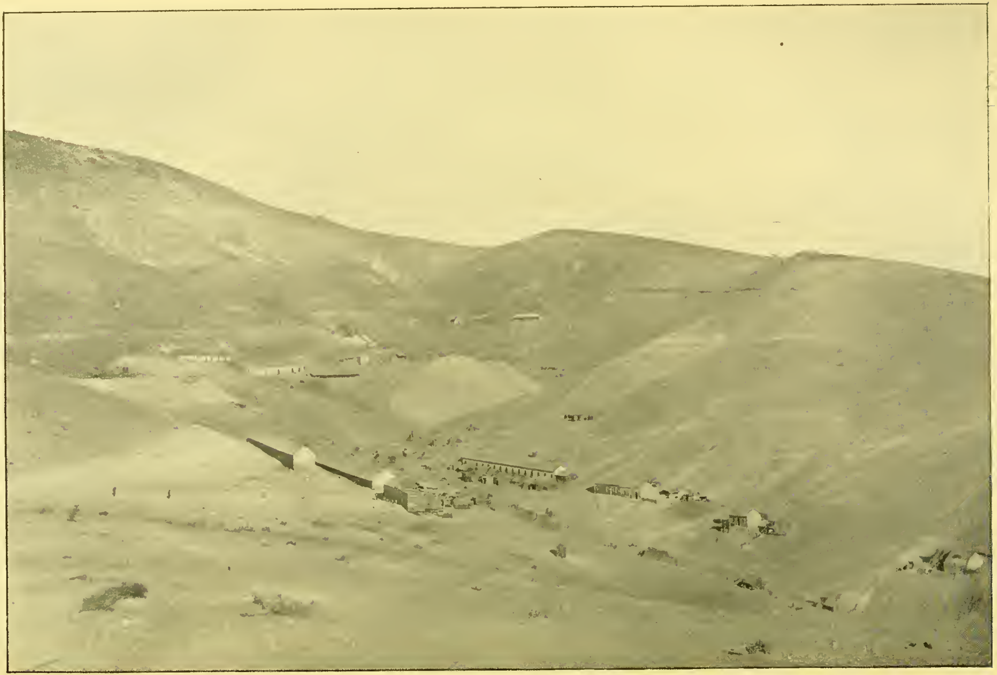

Plate III. Mina Bronces, Atacama, Chile, April 16, 1893. (The cross is above the Lick Observatory Eclipse Station.)

inated, as it is used for fuel. It is a common occurrence to meet a native driving his train of half a dozen or more burros loaded down with this material, of which the roots form the greater part of the bulk. The native sells his wood by weight.

I was quartered at Mina Bronces something over six weeks. The officers of the mine refused compensation for the services rendered by their workmen during this time, and also refused to accept any payment for board and lodging. Messrs. GONZALEZ, IZAGA & Co. have thus given a practical demonstration of their own interest in the cause of science.

Three illustrative photographic views of the station and its surroundings are given in Plates III, IV, and V.

Plate III represents the first near view of the mining camp which the traveler obtains in following the trail from the railroad terminus at Merceditas to Mina Bronces. The camp proper lies in and not far from the head of a cañon on the west face of Cerro Cobre Mountain, at an altitude of 6,600 feet. The location of the Lick Observatory station is indicated by the cross +, and also by the outline of a portion of the 40-foot telescope. The barren and desolate aspect of the landscape is everywhere the same for hundreds of miles along the coast. Trees and other useful vegetation are only to be found in the narrow beds of the comparatively few watered valleys whose sources are in the Cordilleras.

Plate IV gives a general view of the station.

The arrangement of the eye-end interior of the 40-foot telescope is shown in Plate V.

After the eclipse the work of repacking the instruments occupied several days' time. As the observatory at Santiago was to be visited, matters were so arranged that there was but slight chance of the freight going north on the same steamer with myself. The negatives were placed in two boxes, one of which went with the freight, while the other was taken as personal baggage. The chance of total loss by transportation was thus very much diminished. As a still further safeguard, a number of copies were sent at different times by mail.

THE HOMEWARD JOURNEY.

On Saturday, April 29, I left Mina Bronces, all the instruments, with the exception of the chronometer, sextant, and artificial horizon, having been sent to Merceditas the day previous. Before leaving the mine another set of observations for position was made in connection with similar sets of observations at Merceditas and Carrizal Bajo, where I arrived on Saturday night. Here all the instruments, with the exception of the aneroid, were securely boxed and placed in the care of Mr. KING for shipment by the next steamer going north.

As the south-bound boat was not due for several days, there was ample time to visit Vallenar and take the steamer at the port, Huasco, connected with the former city by a railroad.

At Chañarcitos a most agreeable evening was spent with Mr. UPJOHN, Superintendent of the smelting works. The following morning, at Estacion Negro, reached by rail, a carriage with *three* horses was in waiting, and Vallenar was made after a six hours' drive, commanding a general view of the wonderful country which DARWIN has described in his writings and studies. The whole valley and the wonderful terraces of the Huasco River are teeming with life, both animal and vegetable. Practically all the river water is made use of for irrigating purposes; streams are carried even to the very tops of the terraced banks. This river valley is noted the world over for the excellence of its grapes and raisins.

Vallenar, a clean, unique, Spanish-American town, lies in the bed of the river between high-terraced banks, and the astonished traveler from California wonders why it is that the first heavy rain or the rapid melting of a great fall of snow in the mountains does not cause the whole town to be swept out of existence.

The ride to the coast on the newly constructed railroad takes several hours' time, and, aside from the excessive jolting, is full of interest throughout. Huasco is a dirty-looking, poverty-stricken port, which I was glad to leave on the same evening. It so happened that the steamer south was the "Mapoche," returning from a round trip since casting anchor at Carrizal Bajo on March 10.

On the morning of May 6 we entered the harbor of Valparaiso. At the hotel I was cordially greeted by Mr. Wolff (a young Californian, by the way), the correspondent of the New York Herald. Bishop and Mrs. Newman, of New York, and Mrs. Moses, of Washington, D. C., were also at the same place. As we were the only Americans at the hotel, time passed very quickly talking over home and other affairs. The next day we all started for Santiago.

The observatory was visited in company with Mr. Wolff. Besides the ordinary apparatus and buildings, a large meridian circle is at present being put in position. The contemplated work on the photographic chart to be undertaken at this observatory necessitated not only new instruments, but new buildings; the former are already on the ground in boxes, and await the completion of the special brick edifice now in process of construction. In Professor Obrecht I found a most agreeable and dignified astronomer. Nearly the whole of his time is given to class-room work at the university, a State institution, in which he is a full professor, having charge of the Astronomical Department. He has one assistant at present. Time signals are sent out daily, and regular meteorological observations are also carried on.

Dr. Obrecht has written a treatise on Theoretical Astronomy, which is ready for any publisher willing to undertake the task of printing it. From a necessarily hasty inspection of the manuscript, I formed a very favorable opinion of his still unpublished scientific work.

The university is deserving of the highest praise; a number of the various departments were visited. The salaries of the professors are very small, but the honor of being connected with this really creditable institution offers, as I was told, sufficient advantages, in a social way, to make personal sacrifices endurable.

Our Minister, Patrick Eagan, stated that an American lady, living in Chile, was very desirous of building a monument over the spot where Lieutenant Gilliss, of the United States Naval Observatory, made his astronomical observations in the years from 1849 to 1852. Mr. Eagan asked me to aid him locate the place. He had several times visited the locality, but had been unable to obtain the desired information.

Accordingly, in company with Dr. Obrecht, who was asked to join us, we ascended the picturesque mountain, or rather hill, called Santa Lucia, which rises abruptly in the very heart of the city to a height of several hundred feet above the great level plain on which Santiago is built; but, although we searched carefully for any traces which might indicate the spot where the instruments stood, our efforts were unavailing. Many buildings had been erected on the rock since the time Gilliss had occupied it as an observing station. A direct outcome of the Washington astronomer's labors at Santiago is the present large astronomical observatory, the only institution of its kind on the west coast of South America.

By special request a short lecture was given before the "Société Scientifique du Chili" on the eclipse expedition. This flourishing society annually publishes a large volume of "Proceedings," containing original memoirs written by its members. The language used both in the oral discussions and in the society's journal is French.

The next steamer going north, the "Santiago," found me on board. It was in Coquimbo harbor where, while scanning the different ships in port through a field-glass, the name "Melpomene,"* belonging to a formidable, but graceful-looking warship, was seen. One of the many boats which continually swarm about all steamers in port, in the expectation of securing passengers for the shore, was soon on its way to this representative of the great floating forts, the secret of England's power and supremacy the world over.

Captain Parr at once dismissed the boatman, and then personally initiated the Californian into the mysteries of a typical modern war ship. Later, one of the "Melpomene's" boats took us back to the steamer, where the commander was shown copies of the eclipse photographs.

At Carrizal Bajo another pleasant hour was spent with Mr. King and family. Mr. Walker, who came all the way down from Mina Bronces to bid farewell, was also present.

On May 17 the steamer arrived at Mollendo, the port for the interior town of Arequipa, where the Harvard College Observatory station was to be visited. This place has the uninviting aspect common to nearly all the seaports along this coast, with the additional disadvantage of a very unsafe landing place.

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* As will be learned farther on, several of the "Melpomene's" officers took part in the eclipse work at Mina Bronces.

The railroad ride from Mollendo to Arequipa consumes about eight hours. For the first six or eight miles the traveler is carried along the ocean shore; the road then turns into a very fruitful valley running into the interior. About ten miles inland the ascent to the tablelands, 3,000 feet and upward above the sea, suddenly begins. Once on this plateau, the rise toward the interior is very gradual. The character of the roadbed demonstrates that many engineering difficulties of construction have been successfully overcome.

The most striking phenomena of this truly wonderful country are the numberless sand hills, which, separated from each other by distances varying from a few feet to several hundred yards, literally cover the plateau as far as the eye can see.

This sand is believed to be of volcanic origin. The mounds are all of the same form, but vary greatly in size, from a height of only a few inches up to 30 feet or more. Each has a crescent-shaped base, and terminates at the top in a curved ridge formed by the bounding surfaces. They are constantly undergoing a change of position without any considerable change from a typical form. The moving force, a slight air current, is made manifest to the observer in the form of delicate streams of sand, apparently issuing from the top of each pyramid, but in reality driven from the slightly convex side to the slightly concave surface in each case.

In the distance these mounds look just like clouds low down in the horizon. The sky is apparently partially or totally reflected from the heated atmospheric layers close to the earth's surface, so that only these brighter and higher surface features show in the sky-like fore- and background, producing the striking illusion of clouds in the horizon. Just before reaching Arequipa, the traveler has before him one of the grandest scenes to be found anywhere. From the steamer only the snow-covered tops of the *Pichu Pichu* range, of *Misti*, and of the *Chachani* range can be seen, but now, immediately after crossing the divide, the observer is rushing along at the edge and very top of an immense precipice forming one side of a deep cañon, and has before him a vast panorama, illustrative of the great power of some of nature's forces.

In the immediate foreground, and many hundred feet directly beneath, is a rushing torrent; across the gorge, and to the very base of the mountains, more than 20 miles distant, are, to the left, great lava beds, with wonderful contour lines, as though, during the wildest commotion in former ages, the whole surface, then of a semi-fluid nature, had suddenly become frozen solid. More to the right the great volcanic cone, *El Misti*, rises majestically out of a large plain, on which one of the oldest and most interesting of South American cities is located.

Arequipa—built of white volcanic stone quarried near by—is a town of churches. The Fathers are seen everywhere. Church bells are heard at all hours of the day. Prayers and church-going are incessant. The city is, on the whole, neat, extremely orderly, and, as intimated above, extremely religious.

At the hotel the visitor is required to enter his name in the register, and record the object of his coming, how long he expects to stay, age, profession, nativity, citizenship, married or single, etc.

The day after arriving at Arequipa I went out to the observatory, distant about three miles from the hotel, where Professor Bailey and his assistants were found busily engaged in astronomical work.

The *personnel* of the observatory was as follows:

Professor Bailey, Director of the Observatory.
Mr. Bailey, Photographer of the Observatory.
Mr. Mecklenhoff, Assistant.
Mr. Duncker, Assistant.
Mr. Waterbury, Assistant.

The members of the staff all mess at the same table, presided over by the accomplished wife of Professor Bailey.

The observatory is situated on the outskirts of Arequipa, at an elevation of 8,000 feet, and is reached by a narrow, winding road, bounded on both sides by high stone walls, which in the more populated districts form the street-side of the houses occupied as dwellings and shops. The sensations of the traveler in going over these weird, ancient highways of the Incas are of a dream-like character, doubtless produced by a recalling of the vivid mental pictures of this race formed in childhood. And here, at Professor Bailey's urgent and kind invitation, some interesting and never-to-be-forgotten days were spent.

The 13-inch equatorial was being used with great success by the Director in photographing the more remarkable clusters in the southern sky. He kindly offered to make the necessary changes in the objective to adapt the instrument for visual observations, and thus afforded me the opportunity of testing the character of the seeing at Arequipa. To change from photographic to visual work the outer lens is reversed and the distance between the lenses altered somewhat.

Owing to our lack of time, the lenses (which have no adjusting-screws for collimating, bits of paper being used to change the inclination) were not centered accurately. Nevertheless one could still form a very fair estimate of the seeing, which on this occasion was called good by Professor BAILEY.

The brighter stars were surrounded with many well-defined diffraction rings, which did not seem to be affected by the apparently great commotion in the stellar disk and rays—a curious kind of rapid twinkling without blurring.

On turning to the moon I remarked that the seeing was "woolly," the effect of minute atmospheric waves plainly visible in the slight movements of the lunar surface. At the Lick Observatory the same quality of seeing would be classed about 4 on a scale of 5 for best seeing. On no day during my two weeks' stay at Arequipa was the sky continuously free from clouds, and the sky-glare was much more pronounced than it is at Mount Hamilton in favorable weather. I was told, however, that the rainy season was commencing.

THE ASCENT OF CHACHANI.

Learning of my desire to attempt the ascent of Misti, Professor BAILEY proposed that I should wait until June, when he expected to fit out an expedition with the intention of getting to the top of Chachani's west peak, on which no white man had ever set foot, to test its suitability for a permanent meteorological station. Finding that it would be impracticable to prolong my stay until that time, he at once arranged to have the expedition leave the following week.

The fact that all individual experiences at very high altitudes are of real scientific interest, has led me to dwell somewhat at length upon the incidents of this expedition.

The members of the party were: Professor Bailey, in charge, Mr. Duncker, three natives, and the writer. To carry the men and the baggage eleven mules were required—six for riding and five pack-mules. We were to have started at 4 A. M., so as to reach a good altitude before sundown, but owing to the slowness of the natives, it was 7 o'clock before we were on our way. One of the guides started the day previous to select a good camping place for us.

The ascent during the first 10 miles is very gradual—less than 500 feet to the mile. The trail crosses many creek-like depressions, caused by torrents from the mountains during the rainy season. The material seems to be mostly drift, lava, and volcanic sand. From the upper end of this great slope, at the base of the mountains proper, the trail is very steep; in places the rider would feel more comfortable on foot.

On the way up my aneroid refused to register properly after passing the 14,000-foot mark, although the graduations on the instrument run up to 15,000.

About sunset we were actively engaged in making things as comfortable as possible for the night on a small, plateau-like extension of the mountain side, at an elevation of 16,000 feet.

Before leaving Arequipa my aneroid registered 7,775 feet; at 8:30 P. M. the mercurial barometer and thermometer readings were:

Barometer	16.981 inches.	In tent.
Attached thermometer	28.0° Fahr.	
External thermometer	21.0° Fahr.	

When out of the saddle we soon learned that vigorous exercise was very decidedly unwholesome, causing an indescribable sensation, as though one's strength was suddenly failing, and the desire to sit down if only to take breath was almost invariably followed by the act.

At various times during the day I looked up at the sky in the hope of seeing that deep blue color which great altitudes in a clear atmosphere give, but the celestial vault was never free from haze; thin cirrus clouds also at times increased the brightness of the sky. The attempt to see stars in broad daylight was not made, for it would have been useless. During the night a 4-inch achromatic telescope (on a rude wooden altazimuth mounting specially constructed for this occasion) was used on the brighter stars and the moon. While the character of the images was less favorable than at Arequipa, the curious feature of very active commotion in the stellar image without any accompanying blurring, and the diffraction rings, appeared much the same as at the observatory below. The moon's image also had the same woolly, surface-creeping look.

At great altitudes and after sunset the temperature often falls below zero even in the tropics, so that the white traveler in an exposed position cannot keep warm at night with the ordinary covering. Professor BAILEY, Mr. DUNCKER, and the writer were each provided with a sheepskin bag with the wool turned inwards. Each bag completely covered its occupant, with the exception of the head, which was the only part of the body exposed to the air in the tent.

But how about our native guides? I often wondered and still marvel at their remarkable powers of endurance, and their to us peculiar notions as to bodily wants, so completely at variance with some of the most universally accepted sanitary doctrines of the Anglo-Saxon race.

Shortly before retiring for the night I visited their tent. Just in front of the opening they had built a fire, the fuel being a moss-like growth covering the rocks. The three natives were seated around the blaze, with blankets wrapped about *their heads.* The legs and lower part of the body had no extra covering, and the bare toes were in several places protruding through holes in the coarse leather shoes.

I have no record of the temperature at this time, but it could not have been many degrees above zero, with a stiff wind blowing. The next morning all the occupants of our tent reported—entire loss of appetite, a severe headache, a great disinclination to get up. In my own case the headache is ascribed wholly to a restless night, which in turn is attributed to the fact that I did not undress—a very unusual circumstance.

We were not to attempt the ascent to the summit until the second day after our arrival, as Professor BAILEY thought it would be best to rest twenty-four hours before making the final effort. Several experimental trips to neighboring heights admonished us that our energies would be tasked to their very utmost on the following day. Mr. DUNCKER, in company with one of the guides who was to take the transit and camera part way to the summit, reached an altitude of about 16,800 feet. On his return to camp he was taken violently sick, became delirious, and for several hours we were in great distress on his account, there being no outside help nearer than Arequipa. Towards morning, however, he recovered to such an extent that he asked to be allowed to go with us to the top. The danger, however, appeared too great, and he was finally persuaded to remain below.

To test the effect of the altitude upon our physical condition, a number of observations were made upon all three observers. I did not copy Professor BAILEY's record, but give here a few of the notes jotted down at the time.

Wednesday, May 24, 1893. At the Arequipa Observatory—Altitude, 8,000 feet; boiling point of water, 198°. Normal concondition of J. M. S.: Respiration, 16 per minute; temperature of body, 37° Centigrade; pulse ? (65 at Mount Hamilton, 4,200 feet).

Friday, May 26, 1893. At the Camp on Chachani—Altitude, 16,000 feet. J. M. S. has headache and tired feeling; respiration, 17.5 per minute; temperature of body, 38.2° Centigrade; pulse, 103 beats per minute.

These observations were made just *before* getting up from a night's rest (?); the observer was therefore not unduly exerting himself.

On Saturday, May 27, we left camp, with two guides, between 8 and 9 A. M. A short distance up the cañon, almost at the very top of the saddle forming the divide, the snow was so deep that it seemed impossible to get the two mules—which Professor BAILEY and myself were riding—over the pass. Immense bowlders projecting through the snow showed that the danger of losing the animals at this point was very great. Out of sheer desperation we finally managed to force one of the mules through the pass, the animal nearly disappearing from view in the snow whenever it lost its foothold on the more elevated snow-covered rocks.

As the risk of getting the second mule across safely was too great we decided to push on with one animal and take turns walking and riding. At 9:30 A. M. our further progress with the animal was completely blocked by the character of the steep mountain side; bowlders from one to ten and more feet in height covered the entire face of earth above. As the remainder of the ascent could only be made by climbing over the rocks, the animal was left at this place.

Shortly before 10 A. M. Professor BAILEY, who had several times been seized with vomiting, was taken with a more serious attack, due to the great physical effort required in climbing, and could go no farther with safety. We were now at the place where Mr. DUNCKER had left the instrument on the previous day—an altitude something less than 17,000 feet.

As my only malady was a severe headache, I signified my intention of going on alone with one of the guides. The other guide remained with Professor BAILEY, who obtained some excellent views with the camera from this point during my absence.

No adequate idea can be given to the reader of the sensations one experiences in climbing at great altitudes. The physical effort required to raise one's own body causes such a palpitation that the climber is obliged to rest every few minutes. The heart is thumping at an alarming rate and with such force that the sound alone causes a sickening sensation to its possessor, who is constantly expecting that something is going to break. But so long as the body was physically capable of obeying the commands of the will, so long was it resolved to keep on towards the top. The native with 30 pounds of instruments on his back seemed to have but little difficulty in scaling the rocks.

The sun was on the meridian when I asked the guide whether in addition to his other load he could without inconvenience carry the mercurial barometer, which up to this time had been slung over my shoulder with a strap. He smilingly relieved me of the burden.

It was thirty-five minutes past one o'clock when we stood upon the highest pinnacle of Chachani's west peak; the wind here was blowing at the rate of at least 40 miles an hour—and icy cold.

Whether it was the feeling of relief at having successfully reached the top, that caused the traveler to feel as well as he had ever felt is not known, but the headache was gone, as was also the listless, tired condition which seems almost to master one in very high altitudes; he could and would have gone much higher then and there had the opportunity presented itself.

Far to the southwest the Pacific vies with the bright horizon for supremacy in brilliancy—indeed, the line of division between the two can only just be recognized. At a less distance in the same direction some mountains on the other side of the great plain rise above the flat-looking surface 10,000 feet lower down, the depressions in these mountains and the plateaus beyond being covered with great stretches of bright, volcanic sand and the numerous mounds already mentioned. Still nearer in the foreground, but more to the left, Arequipa, the white city, appears as a beautiful constellation of numberless white specks, most condensed near the center and surrounded on all sides by a green, made gorgeous through distance.

The large winding cañon separating Misti from Chachani appears as a rill-like formation, which, on its way to the ocean, passes through the western portion of Arequipa.

The spectator can scarcely realize that the farther bank of this seemingly insignificant rill carries the railroad from which the imposing, indescribable view was obtained, mentioned on page 20.

Farther to the right, in the immediate foreground, are the great lava beds, 8,000 feet above the sea, over the whole expanse of which the eye can now sweep from an additional height of nearly two miles vertically above them.

To the apparent east of Arequipa the grand snow-covered range Pichu Pichu, with peaks rising to heights of 17,000 feet, and distant perhaps 30 miles, stands out in solemn grandeur against the horizon. Still farther to the east, but at one half the distance, is the sublime, mysterious, gigantic cone, the volcano El Misti, with a faint column of smoke issuing from its summit at an altitude of 19,000 feet. On the southwest face of the slope which forms the base of this mountain, and distant about 10 miles from the crater in an air line, is Arequipa.

Still farther to the left, and seemingly within a stone's throw, but in reality many thousand feet distant, is the east peak of Chachani (with the intervening saddle-like depression 2,000 feet deep), cutting off some ten degrees of the horizon in altitude.

The reason the observer is so amazingly deluded as to the distance is that there is absolutely nothing on the snow-covered tops of the great precipices to enable him to form an estimate of how far the mountain is away. There is no tree, shrub, nor, indeed, life of any kind whatever, at home here; and the absorption of the atmosphere is so slight that for a few miles no sensible effect is produced in a cloudless sky.

The remaining arc of the horizon incloses a country the observer beholds for the first time, and over which hover black, angry-looking clouds. Distant about 50 miles to the northeast, beyond the intervening low-lands here and there visible between the clouds, is a range of mountains which most provokingly cut off the view the observer half expected to obtain of Lake Titicaca, for the spectator is considerably more than a mile higher than the level of the lake.

Farther around to the north is an enormous snow-covered cone, the direction and elevation of which is indicated in the measures recorded farther on.

To make this visual survey, probably not more than a minute was required; it was getting cold and there was other work to do.

We had ascended the mountain on the leeward side and so were protected from the frigid blasts, but once on top I longed for my great overcoat to cover the short, light jacket.

My *barefooted* companion, who, during the trip up the mountain through the snow, had never uttered a word of complaint, kept muttering to himself "*mucho frio,*" "*mucho frio.*" I now hastily mounted the transit on the slightly concave, nearly horizontal surface of the highest (easternmost) of four peaks surrounding a crater-like depression, and made the pointings recorded below on the several objects named. The mercurial barometer readings were at once made. The attached thermometer was—like the barometer—incased in a leather box, so that the indicated temperature, while being at least 7° higher than the external air, gave the correct reading for reducing the height of the column of mercury.

Bar., $15^{\text{in}}.506$.
Att. therm., 38°.

At 7 A. M. on the morning of that day the readings in camp were:

Bar., $16^{\text{in}}.886$.
Att., 30°.2.

And at 6 P. M.:

Bar., $16^{in}.910$.
Att., 35°.
Ex., 28°.

Flash-light signals were sent down to the observatory, where simultaneous observations were being made. As learned afterwards, Mr. BAILEY was observing our motions with the 13-inch equatorial, and took several photographs with the same telescope.

The measures with the surveyor's transit follow:

Name of Object Observed from the Top of Chachani.	Readings of Circles.	
	Azimuth.	Vertical.
Observatory in Arequipa	39° 36′	—10° 0′
South peak of Pichu Pichu	0 34½	— 1 34
Volcano Misti	351 35	+ 0 30
East peak of Chachani	311 15	+ 8 20
Large snow-covered cone about 40 miles away	190 50	— 0 20

I would have made more pointings, but suddenly became aware that unless the instruments were at once replaced in their cases, my whole body would soon be too numb from cold to get away from the place at all. The murmuring complaint, "*mucho frio*," became louder. Snow commenced to fall in such volume that the great peak of Chachani could no longer be seen. A suddenly obscured sun also caused an alarming increase in the personal discomfort of the only two living creatures within miles.

The complete protection from the icy blasts, after leaving the summit, and the exertions of the body in making the descent, soon brought about a vigorous and most agreeable circulation of the blood.

It should be mentioned that on the *downward* trip, without any undue exertion, I kept constantly in advance of the guide.

Professor BAILEY had walked all the way back to camp, and we found the mule, which he had kindly left for me to ride, still tied to the rocks. We managed to get the beast through the pass without accident, and late in the afternoon arrived at camp, where preparations were in progress to start for Arequipa that night, but after talking the matter over we came to the conclusion that the risks run in going over the trail after sundown, even with a full moon, would be greater than those taken by remaining until morning.

It must be remembered and specially emphasized that during all this time, both by day and by night, the pulse continually registered in the neighborhood of 100 beats per minute. Our only food was a few crackers and a cup of coffee at each meal; hunger was wholly unknown. As a result of this condition of things there existed an uneasy feeling as of physical weakness, which naturally appeared to be growing more serious every moment.

During the night, the third of our stay in camp, I had occasion to regret that Professor BAILEY's first intention had not been acted upon, for we had a severe snow-storm, which threatened every moment to tear the tent from over our heads. Indeed, that used by the guides was torn down, and the poor fellows were obliged to squat in the snow for the remainder of the night, with the thermometer only 5° or 6° above zero. When we got up in the morning, the whole interior of the tent was covered with drifted snow, which was several feet deep in places on the outside, and in which all our traps lay buried. Here, again, the incapacity of the natives was made exasperatingly evident, for do what we would they could not be induced to work in earnest until long after sunrise. It was bitterly cold, and packing occupied nearly two hours' time. All traces of the trail were obliterated, and we trusted entirely to the animals for finding the path. In fact, the pack-mules were in advance on the downward march. During the night the snow line had descended more than 2,000 feet. We reached the observatory in fine condition towards sundown, ravenously hungry, and wondering why we had felt so miserable up in the sky-lands.

I have no record of the simultaneous meteorological observations made at the observatory, but a provisional reduction by Mr. MECKLENHOFF makes the height of Chachani's west peak a few feet over 18,100. Several facts pertaining to our experiences in the upper atmosphere are worth recording here. As long as the traveler is carried on the back of some beast, no discomfort of any kind is experienced up to 16,000 feet, and probably none would be felt up to any altitude the rider could be carried by a living creature. It seems to be the physical exertion made in climbing that unfits the dweller of the lower regions for making the highest ascents. Since the expedition to Chachani, for instance, Professor BAILEY has succeeded in reaching the top of Misti* by riding all the way to the summit, 1,000 feet higher than the west peak of Chachani.

Where, as in the case of the last mentioned peak, it is impossible to take an animal, all unnecessary physical effort, like trying, for experiment, to run a few steps in climbing, should be carefully avoided. Hours should be given to climb heights which at ordinary levels can be reached in one fourth of the time, provided the return journey to camp can be accomplished before sundown. We lived on coffee and crackers for three days, although we had provisions enough in the way of meats and canned goods to last the whole party for ten days.

During the trying times on Chachani I learned to appreciate the calm, dignified, and sterling qualities of Professor BAILEY. In his ideal home I experienced the first complete rest since leaving the Lick Observatory.

Mollendo was lost to view on May 31, as the steamer "Arequipa," sister ship to the "Santiago," hurried on her way northward. Panama was reached on June 14, and four days later I left Colon for New York.

In an expedition in which the party consists of a single individual, who has continually to be on guard to see that even the minutest detail is personally attended to, and where a single omission or mistake may cause the most serious consequences—so far as the success of the expedition is concerned—the conscientious individual can have no real rest. Several months' experience of this kind must be undergone to be appreciated.

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*The volcano Misti has since been chosen as the site for the meteorological observatory, a most excellent location in all respects except one—the heated air, from the crater, will render the thermometric results unreliable whenever the wind is in a direction from the crater toward the instruments. The difficulties attending a periodical ascent of Chachani are probably too great, and the cost of cutting a trail to the top was doubtless deemed too expensive, to make this peak desirable as a station for continuous observations.

Acknowledgments.

The success of the Lick Observatory expedition to Chile is largely due to the efficient and willing aid given by those with whom I came in contact—more particularly to:

The Regents of the University of California.

Professor Edward S. Holden, Director of the Lick Observatory.

The Government of Chile.

Hon. Wm. M. Pierson, of San Francisco.

Mr. Robert Bruce, of San Francisco, member of the firm of Balfour, Guthrie & Co.

Mr. Wm. Henderson, of Valparaiso, of the firm of Williamson, Guthrie & Co.

Mr. John King, British Consul at Carrizal Bajo, Chile.

Messrs. Gonzalez, Izaga & Co., owners of the Mina Bronces Mine.

Mr. R. A. Walker, of Valparaiso.

Mr. Felipe Bray, Captain of the mine.

Mr. E. J. Molera, C.E., San Francisco.

Señor Guerrero, Consul for Chile, San Francisco.

Mr. W. F. Gale, Paddington, N. S. W.

Hon. J. J. Aubertin, London, England.

Mr. A. Hole, London, England.

Mr. Tirepegui, Santiago, Chile.

Lieutenants Brown, Bodger, and Wilson, R.N., H. M. S. "Melpomene."

Mr. Martin, Cerro Blanco, Chile.

Mr. Wolff, correspondent New York Herald, Valparaiso.

As stated in the beginning of this report, the undertaking was made possible through the liberality of a San Francisco lady who furnished the means to defray the cost of the expedition in the field. Astronomical science is thus much indebted to Mrs. Hearst.

OPERATIONS AT THE ECLIPSE STATION.

On the morning after my return to Mina Bronces, work was at once commenced at the place selected for the location of the astronomical instruments—it will be called the Upper Station, to distinguish it from the other headquarters at the mining camp proper, where observations were also made, which will be called the Lower Station.

As several different lines of investigation were to be carried on with the aid of the 6-inch CLARK equatorial, this instrument was the first to be placed in position. Only the upper portion of the iron mounting, containing the driving-clock, etc., was taken to South America; the lower part, or pier, was made of wood, strongly braced, with the four legs resting upon the rock. As the maker had provided no means of reversing the direction of diurnal motion made necessary by the elevation of the south pole instead of the north above the local horizon, I reversed the ratchet on the clock's winding axis, and led the cord for carrying the clock weights over a pulley through one of the doors to the clock chamber. Half a day's work was required to make these changes, which had not occurred to me before leaving Mount Hamilton. While making the observations for azimuth of the polar axis, I was at once very forcibly struck with the extreme steadiness of the atmosphere—not the slightest tremors were perceptible in the focal images, and the very highest power used plainly gave evidence that the superior limit for magnification was considerably greater than the available eye-pieces would give; only the wind and want of light-gathering power of the objective seemed to prevent one from satisfactorily making the most difficult tests. Later, however, on some nights, the seeing was not first class. As remembered now, this was the observed case on two or three occasions during my stay. Nowhere has the writer met with such uniformly good seeing in the daytime. The stellar disks were unusually steady, and the sun's image formed by the 6-inch CLARK lens (and later on in the 40-foot telescope) was so sharply outlined on the white cardboard used for projection, that it appeared more like an engraving than an optical image. The sun-spots, faculæ, and the mottled surface were revealed with great distinctness.

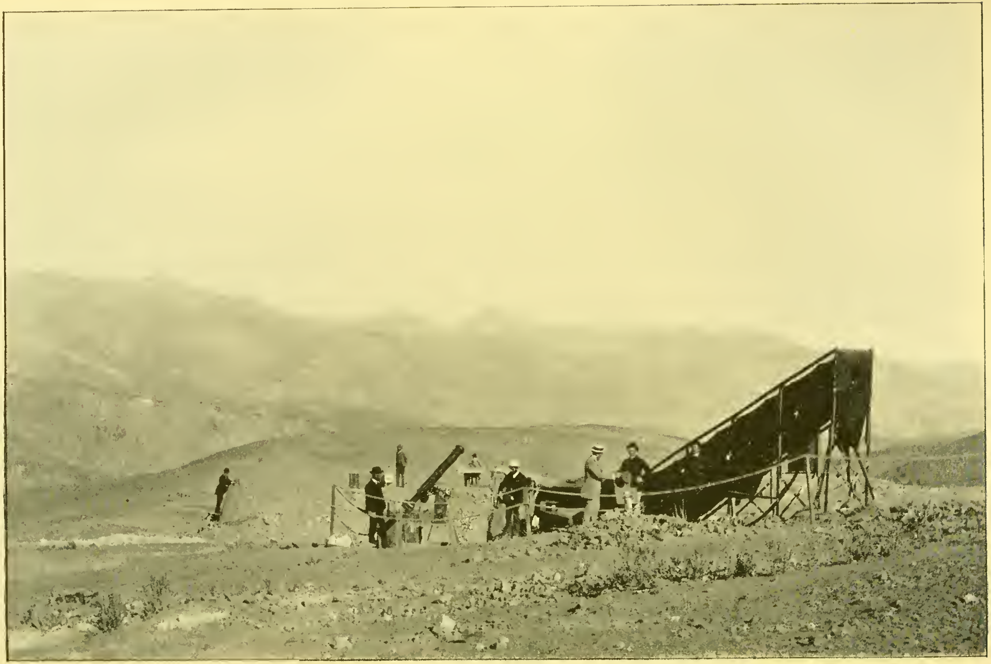

Plate IV. Lick Observatory Eclipse Station, April 16, 1893. (Mina Bronces, Chile.)

The telescopic appearance of a first magnitude star observed in the daytime was always such that the observer's first impulse after sighting the object in the telescope was to glance along the outside of the tube in the expectation of being readily able to catch it with the naked eye. However, I never could be quite satisfied that any fixed star was seen without optical aid when the sun was near the meridian.

One of the lines of work to be undertaken with the DALLMEYER lens was a series of long-exposure photographs of some of the more interesting configurations not visible at the Lick Observatory. In this work the DALLMEYER camera was strapped to the tube of the equatorial, and the latter used as a guiding telescope.

Several long series of observations on *Sirius*, for determining the amount of the atmospheric absorption of the photographic rays, were made on a number of nights, *Sirius* being photographed at intervals of a few minutes each from about the time of its meridian passage to its occultation by a mountain ridge in the west. Several different plates were used on each night, and each plate contained a complete set of exposures for deducing an independent value of the absorption.

The pointings were very readily and quickly made by bringing the image of *Sirius* successively to the center of each square of a series formed by two sets of heavy black lines ruled on the ground glass placed in the focus of the 6-inch CLARK equatorial, the driving-clock running continuously during the exposures of a given set.

A number of 5^m exposures giving the naked-eye (and fainter) stars of the regions about the south pole were also made with the DALLMEYER lens.

During the day the whole time was usually occupied in work on the 40-foot telescope. The spot of ground chosen for this instrument required considerable alteration before the framework was placed in position.

As there might be serious atmospheric disturbances in the image unless the line of sight was at a considerable distance from the ground, the location was selected with special reference to the inclination of the surface, which was considerably less than I at first thought sufficient.

To reduce somewhat the height of the objective end of the telescope as well as to give greater stability to the whole structure, the eye end was lowered about two feet by excavating the rock, which at this place was largely broken stone from a former excavation. After the necessary preliminary observations for obtaining the place in the local sky that the sun was to occupy during the eclipse had been made, the skeleton framework was first placed in position and firmly tied to the ground by strong wire guy ropes fastened to the top of every upright and running to as many different staples driven into the rock.

The canvas which was to form the inclined portion of the tube was next drawn through the frame and fastened to it by means of cords. The cubical room at the lower end of the telescope was formed by slipping the already patterned canvas over the frame-work so that the top and three sides of the cube were completely covered, the laps of the opening 4 by 4 feet on the fourth side were then tacked to the same frame that held the lower end of the inclined tube. The bottom and sides of the excavated parts of the room were plastered with "barro" to prevent the formation of dust as the observer moved about. This plastering also served to give great rigidity to the lower end of the tube.

An opening, just wide enough to admit the observer, cut through the north face of the cube, was covered with a light-proof door on hinges, for giving ready access to the interior.

The wooden pier for carrying the objective lens consisted of a strongly braced tripod, the legs of which were set in masonry formed of pieces of rock and clay. This mortar is the "barro" of the natives.

The object-glass was mounted, with three adjusting-screws, on a slide which was securely fastened to the end of a vertical rod clamped to the tripod. The top of the tripod was only a few inches below the lower side of the tube, through which the rod passed without direct contact with the canvas, so arranged, however, that no stray light could enter the tube through this aperture.

Close to and directly in front of the frame carrying the objective was placed a black cloth partition (sewed to the sides of the tube), with an aperture slightly larger than the objective. At the extreme upper end of the frame-work, about one foot

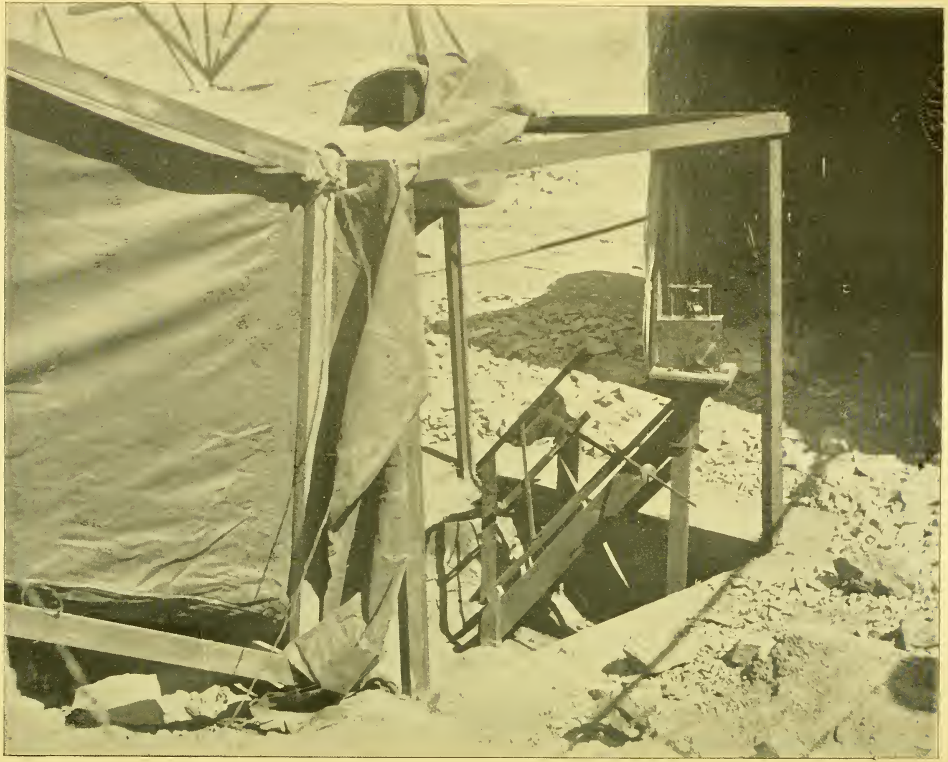

Plate V. Lick Observatory Eclipse Station, April 16, 1893. (Eye-end interior of the 40-foot Telescope.)

from the objective, a second (cardboard) partition, with an aperture of about eight inches, served to protect the lens from the light of sky-areas not included in the field of view on the photographic plates. The under side of the tube was protected from direct solar light by a curtain suspended from the end of the telescope. No vibration of the main structure could in any way be communicated to the mounting of the lens, and the objective was, in turn, protected from the wind by the tube itself.

The skeleton frame-work for the photographic slide was so constructed at the Lick Observatory that when it was placed on its three legs the inclination and direction of motion referred to the local horizon at the eclipse station was approximately correct. The plane of the slide was first collimated by causing the light of a lantern to be reflected back from this plane to the observer (stationed at the upper end of the tube and looking down its optical axis). An ordinary plane mirror, mounted (like the photographic plates) on the slide, was used as a reflector.

With the aid of a steel tape-line the proper position of the objective was next determined by shifting the lens along the optical axis until the distance from the plane the sensitive film was to occupy to the inner surface of the lens was 40 feet 1.2 inches. The objective was then collimated in a similar way, the observer being now stationed at the lower end of the telescope, in line with the center of the slide, the glass faces of the objective forming the reflecting surfaces to be collimated.

To accurately obtain the true direction of motion of the stellar focal images a low-power eye-piece which could be clamped to the center of the slide was used in visual observations. The inclination of the guides was changed until any given star described the same chord across the field of view at the two extreme positions of the slide.

The required linear velocity was first found by computation, using the sun's hourly motion (as given in the ephemeris for the time of the eclipse) and the focal length of the lens as known quantities. The motion was, in other words, so regulated that the linear distance moved over by the slide during a given interval of time was exactly the same as the computed distance the eclipsed sun's image would move over during the same time. To allow for the slight continuous change in the declination of the sun during any given exposure, a very slight (computed) change in the observed diurnal direction of the slide was made by inserting a wedge of given thickness under one extremity of the guides, causing a known rotation about the other extremity.

To render it still more certain that no systematic errors had been made in the theoretical and practical work, a number of comparatively long exposure photographs were made on 8x10 plates. Visual observations of stellar images seen through an eye-piece fastened to the moving slide were also made.

To give great rigidity to the frame carrying the slide, as well as to prevent any subsequent accidental disturbance of the adjustments, the three legs were permanently fastened to the rocky floor with "barro," as in the case of the tripod for the objective.

A photographic reproduction of the lower interior end of the 40-foot telescope, showing the actual position of the slide at Mina Bronces, is given in Plate V.

In order to obtain a naked-eye view of the corona to secure data for a direct comparison with a similar observation made at Cayenne in 1889, it was necessary to arrange for some kind of an opening allowing a clear view of the sky near the eclipsed sun. A wooden box, just large enough to completely inclose the observer's head, was placed on top of and fastened to the southwest corner of the room in an inverted position.

The observer, standing erect on a projecting rock in that corner of the room, could then obtain a view of the sky through a slot cut in this box. A flap, held in position by a rubber band, covered the opening when the observer was otherwise engaged. As a still further precaution against any stray light getting through this aperture while the observer was at the opening, a piece of black cloth was hung diagonally from the ceiling so as to form a separate inclosure in one corner of the room, which the observer could enter or leave by simply pushing aside the curtain-like wall of this auxiliary chamber.

During the day, in full sunshine, I often noticed (when in the telescope) that when everything was made as dark as possible considerable light would find its way through the canvas, and while it was probable that no appreciable effect from this leakage would be produced during the total phase, still, to insure a higher degree of safety, the whole interior of the cubical room and about six feet of the inclined portion of the tube were lined with a second coat of black cloth. I found it essential to put some extra cross-pieces in the frame-work to prevent the wind from causing too great a strain upon both the skeleton frame and upon the canvas. As wood is very scarce in this locality, one of the largest boxes was cut up to obtain the material for this purpose.

It was also necessary to build a rope fence around the instruments to protect them from the horses and goats running at large. This same barrier also served to keep the good-natured but inquisitive natives at a proper distance without being under the necessity of continually admonishing them to stand back.

From the very first day Captain Bray placed a man (native) at my service. José could not speak or understand a word of English, but we nevertheless managed to make each other's meaning known. One of us was always on guard, José being only absent at meal times. A small hut (partially shown in Plates IV and V) was erected for him just at the lower end of the telescope, and here he was the most admired and most important native in the whole mining village. I found him very trustworthy and intelligent, but like all of his race, not over inclined to labor with a will when left to himself.

As all the photographic work on the original negatives was to be done at the eclipse station, suitable quarters for a dark room were at once placed at my disposal by Captain Bray. The room, 25 by 30 feet or so, has two deep set windows and a double door entrance, all admirably adapted for shutting out the daylight by means of double screens. The arrangements were made unusually complete, considering the temporary character of the station. The water from the mine was so largely impregnated with foreign matter held in solution that—aside from its doubtful value for making the developer when filtered—every experimental plate after development and washing would be covered with a fine coat of sediment, which had to be removed with a camel's-hair brush. Later on, however, the plates received a final washing in either filtered or distilled water.

Fortunately a large number of empty two-gallon glass bottles were found stowed away. These were kept filled with distilled water daily secured from two leaks on the top of the steam boiler. The most advantageous conditions for securing the best possible results were found experimentally in the development of many negatives of interesting everyday life taken on the daily trips to and from the upper station.

The formula for making the developer is the same as the one largely used at Mount Hamilton for some time, and which has been found to give very satisfactory results. This developer is made as follows:

$$\mathrm{A}\left\{\begin{array}{l}\text{Water, 60 oz.}\\ \text{Hydrochinon, 1 oz.}\\ \text{Sulphite of Soda, 5 oz. (crystals).}\\ \text{Bromide of Potassium, 5 grains.}\end{array}\right.$$

$$\mathrm{B}\left\{\begin{array}{l}\text{Water, 16 oz.}\\ \text{Caustic Potash, } \tfrac{3}{4} \text{ oz.}\end{array}\right.$$

$$\text{Developer} = 8\ \mathrm{A} + \mathrm{B}.$$

That is, eight parts of solution A by volume is to be used for one part of B. In making solution A it was always kept heated in a hot water bath until the constituents were completely dissolved. This requires several hours' exposure to heat at the boiling point of water.

To insure a uniform and rapid initial flow of the developer each plate was first immersed in a bath of distilled water for a few seconds, and then immediately transferred to the developing bath, which, for each of the large plates, contained about 70 ounces of developer.

All the photographic plates to be used on the day of the eclipse were from the Seed Manufacturing Co., and of the highest degree of sensitiveness—No. 26 X of their scale.

The detail of both the inner and outer corona were to be photographed by giving a graded series of exposures, from the shortest possible to moderately long. The wisdom of selecting this course, instead of using plates of varying sensitiveness, is shown by the complete record of coronal detail (from the moon's limb to a distance of several diameters from the sun's center), to be seen on the Lick Observatory negatives.

It was not until about a week before the eclipse that all the instruments were in readiness for the critical moment. The photographic foci of both the 6-inch CLARK equatorial and the 6-inch DALLMEYER lens were carefully re-determined. Mr. WALKER was instructed in the use of the 6-inch equatorial. Captain BRAY practiced with the DALLMEYER, and Mr. TIREPEGUI used the 5x7 camera.

The experimental photographs of the moon taken by Mr. WALKER with the equatorial gave every promise that he would do his work satisfactorily during totality. Mr. KING was to come up from Carrizal Bajo on Friday, April 14, in order to have some preliminary practice with Captain BRAY in the manipulation of the DALLMEYER. I had given up all hope of seeing Mr. GALE, who was also to join me, for in a letter received only a few days before from N. S. W., he stated that he had been unable to take the regular steamer for Valparaiso, but might possibly reach Chile in time for the eclipse. I was agreeably surprised on April 14 by the arrival of the following volunteer assistants: JOHN KING, Esq., British Consul at Carrizal Bajo; W. F. GALE, Esq., Amateur Astronomer from Paddington, N. S. W.; Hon. J. J. AUBERTIN and his private secretary, A. HOLE, both from England. On the following day (Saturday) the observing force was still further strengthened by the coming of three officers from H. M. S. "Melpomene," Lieutenants BROWN, BODGER, and WILSON. The Commander of the "Melpomene," Captain PARR, remained at Merceditas to observe the eclipse at that point, he not having any convenient means of reaching Mina Bronces. His lieutenants, I believe, walked to the mine.

During the night of April 15–16 I remained at the upper station with JOSÉ and Mr. CURMEY, a handy young Englishman employed at the mine. After dark all the holders for the different instruments were filled with plates taken from newly opened boxes and properly marked; a corresponding mark in heavy characters was made with white chalk on each covering slide. It was past midnight when this work (done in the 40-foot telescope) was concluded. After a refreshing sleep of five hours the life of the camp was again bustling with activity in the clear, quiet morning twilight. The volunteers were on hand early, all eager to do their very best. I felt very proud of the little army of scientific assistants, and quite confident that if all did not go right during totality, the fault would not lie with the weather, nor be due to a want of enthusiasm and earnestness in the observers.

Every sign gave promise of an unusually clear sky. Not a cloud was to be seen. The coast fog, which ordinarily covered the lower country towards the ocean, was absent; there was almost no wind to disturb the freely exposed instruments, or to raise the dust. Captain Bray had, at my request, ordered the fires to be drawn from the boilers at the mine at three o'clock that morning, so that smoke, which often drifted towards the upper camp, could cause no mischief. The horses and goats at large were driven to a distance where the dust they were continually raising could not come between the observer and the sun. The hundreds of anxiously inquisitive natives were told by their priest to occupy a little elevation on the leeward side of the station, and distant a hundred feet or more from the telescopes.

On the windward side, at perhaps a distance of an eighth of a mile, a guard was placed, who was to command all parties approaching from that direction from below to take the western trail to the station, and to prohibit any one from coming between himself and the telescopes. This precaution was made necessary by the frequent passing of both mounted and unmounted natives, and the accompanying danger from dust.

While I had taken every precaution against avoidable errors, the outlook seemed so very favorable that I was forced to feel that if the best results were not obtained the fault would still be my own, and a somewhat disquieting feeling once or twice asserted itself. I have lived long enough to know that even the most careful observer and computer will at times repeatedly make the same mistake, without being able to detect the error at once, or indeed to recognize that an error has been committed.

All the observations and computations for geographical position, for local time, for the pointing of the great telescope, had been made by myself, in a strange country (where, in spite of a knowledge to the contrary, the *heavens* would appear to revolve from west to east),* without having any one to check my results.

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*It is an interesting fact that during the whole time of the stay at Mina Bronces my sense of direction differed about 180° from the true direction. Every day the sun seemed to rise in the west and set in the east. That this

All the instruments, with the exception of the 40-foot telescope, could be readily shifted and made to follow the diurnal motion of the sun so that in case the actual pointing was in error, it could at once be corrected. The great telescope was, however, immovably tied to the rock by iron bands, fixing its direction. I confess to having asked myself several times, "Will the sun's image fall centrally upon the photographic plate at the critical moment?" I was, of course, confident that it would do so, but confess to having had an uneasy feeling about the matter.

The observers* were stationed at the various instruments, as follows:

Instruments.	Observers.
40-foot telescope.	J. M. SCHAEBERLE.
6-inch Clark Equatorial.	Messrs. GALE and WALKER.
6-inch Dallmeyer.	Messrs. KING and BRAY.
5 x 7 camera.	Mr. TIREPEGUI.
4 x 5 camera.	Mr. HOLE.
Timekeeper.	Mr. CURMEY.

Hon. J. J. AUBERTIN was seated at a table supplied with a thermometer and materials for making a naked-eye sketch of the corona.

For observing the first contact with the 6-inch equatorial, a low-power eye-piece was temporarily fastened to the frame which, later on, contained the photographic plate-holder. I first recognized the indentation caused by the moon's limb at $1^h\ 38^m\ 52^s$ chron. time, the correction to reduce to local sidereal time being — $4^h\ 40^m\ 43^s$. About fifteen minutes before the beginning of totality I entered the great telescope in order to get accustomed to the interior darkness. The large crescent-shaped image of the sun's uneclipsed area was already projected against

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seeming reversal of daily motion was not wholly due to the fact of my being south of the sun, is apparent from several other considerations. At Cayenne (in 1889), for instance—in north latitude, with the sun near its greatest declination south—the same conditions existed; *Polaris*, when visible, seemed to be just a little above the southern horizon, with all the well-known stellar configurations near it. At Carrizal Bajo, on the other hand, the true and seeming directions were the same. So strongly pronounced is this psychical phenomenon in my case, that in any given locality (without reference to celestial or terrestrial instruments of information), one direction, and only one, naturally agrees with a seeming north line, and this line may differ from a true north line by any angle.

*In the early morning of April 17, the photograph, reproduced in Plate IV, was taken to illustrate the positions the observers, at the smaller instruments, occupied during totality.

the lower portion of the canvas tube, and moving rapidly towards the great slide. Several minutes before totality, as I remember it, the corona was seen projected on a screen. Just as the image was central on the slide the clock was set in motion; the black cloth covering the pile of eight pasteboard boxes in one corner of the room, removed, and the first box placed on the slide ready for the first exposure. A few seconds later, at the instant the sun was completely eclipsed, I gave the signal for the observers at the other instruments to commence making their exposures, and at the same time very quickly removed and replaced the cover of the first of the 18 x 22 inch plates. I estimated the exposure time to be about one quarter of a second. This box was then quickly placed in a large box in another corner of the room, and the second plate exposed. After the last exposure the large box now containing all the plates was carefully covered so that no light could find its way to the interior during the remainder of the day. While the 32^{s} exposure was in progress I hastened to the peep-hole and obtained an excellent naked-eye view of the corona. No words of mine can do justice to the quiet grandeur of the scene. At Cayenne (Crocker Lick Observatory expedition) in 1889 the corona did not impress me with the same feelings, probably because of the less favorable atmospheric conditions. As I recall it, my Mina Bronces peep-hole commanded an area of at least 15° on all sides of the sun, yet the whole naked-eye field of view seemed to be filled with coronal light, most intense at the moon's outline, and first gradually, then rapidly, fading in brightness with the distance.

The following are the approximate times of exposure of the plates taken with the 40-foot telescope:

Number of Plate.	Duration of Exposure.	Approximate Time after Beginning of Totality.
1	0^{s}.25±	2^{s}
2	2 .0	16–18
3	4 .0	32–36
4	8 .0	50–58
5	16 .0	72–88
6	32 .0	102–134
7	24 .±	148–172
8	0 .25±	186±

The last plate was exposed about a quarter of a minute after third contact. I was alone in the telescope during the whole time, and not the slightest hitch occurred in the programme. I only regret that more plates were not made available, as a number of very interesting phenomena could have been photographed before the second contact, and also after the third contact, as is beautifully shown on negative No. 8.

The duration times of exposure were determined by counting the number of beats given by Mr. CURMY (watching the chronometer), who, at intervals of one second, struck a wooden box with such force that the sound could be readily heard by all the observers.

Each one had been taught to begin all his own exposures with his own count "zero," and to stop the exposure at the number of seconds corresponding to the heavy chalk mark figures on the plate-holder slide. These characters were always either, In., 1, 2, 4, 8, 16, or 32. In this way there seemed to be less danger of confusion about the duration of the separate times of exposure to be given.

At the 6-inch CLARK equatorial (aperture reduced to three inches), Mr. WALKER inserted the plate-holder and drew the slide; he then signaled Mr. GALE to begin the exposure, which was done by removing the cap over the objective end of the telescope; at the end of the exposure Mr. GALE would give the signal to Mr. WALKER to push in the slide, remove the plate-holder, and insert the next plate. As this was the only instrument whose mounting was such that there was great danger of disturbing the telescope pointing during the critical time, I particularly requested both observers to make sure that the pointing was all right by looking through the finder from time to time. As the negatives show, the telescope was seriously disturbed and unclamped after the first exposure, so that for the remaining photographs the images are not central, and a portion of the outer corona is cut off by the edge of the field of view. In the longer exposures the drift of the image obliterated the finer details. Only on the first plate is the image central. Instead of correcting the suspected disturbance at once, the observers finished the programme and Mr. GALE found time to make a naked-eye drawing of a portion of the corona. Mr. GALE suspected the error, but relied upon the statement of Mr. WALKER that all was well. Mr. WALKER had never used a telescope before coming to Mina Bronces.

Assuming that about one quarter of a minute was required to make the naked-eye sketch, the approximate times of exposure would be about as follows:

Number of Plate.	Duration of Exposure.	Probable Time after the Beginning of Totality.
1	$0^s.25$	1^s
2	1 .0	11–12
3	2 .0	22–24
4	4 .0	34–38
5	8 .0	46–54
6	16 .0	64–80
7	32 .0	90–122
8	0 .25	132
9	1 .0	142–143
10	2 .0	153–155

In response to my request for a written statement from each observer, Messrs. GALE, WALKER, and AUBERTIN handed in "Reports," which are here printed in full.

REPORT OF MR. GALE.

Notes upon the Total Eclipse of the Sun, observed at Mina Bronces, Jarillas, Chile, 1893, April 16.

The station selected being situated at an altitude of 6,600 feet, the atmospheric conditions proved of the highest class, the sky being absolutely free from clouds, smoke, or haze. The sun rose above the ridge to the east of the observatory with dazzling brilliancy. No diminution in the illumination of the landscape was apparent until the sun's disc was more than half obscured.

About fifteen minutes before the second contact it was remarked that the brightness resembled the summer sun in Scotland. After this the sunlight became rapidly less and surrounding objects assumed a leaden hue. At approximately two and a half minutes before the commencement of the total phase, I perceived the moon's shadow above the hills on the western horizon. Its shape became rapidly definite as an immense inverted cone, which ten seconds before totality included 50° of the horizon. It resembled an immense storm cloud, and gave the impression of a much more intense darkness than was experienced after the complete obscuration of the sun.

The shadow bands were seen by me fifteen seconds before the shadow reached us, as a faint shimmering upon the ground at my feet. A few minutes later the delicate gradations of light and shade increased to strongly marked, wave-like pulsations. The area over which they were visible from my standpoint was, roughly, about sixty feet square. The cold very perceptibly increased as totality approached, but no wind was experienced throughout the eclipse. Beyond the shadow the appearance of the horizon was normal during the whole phenomenon.

In the period of totality the landscape presented a slaty tint, giving to all nature an unnatural and sickly aspect. The illumination at mid-eclipse was sufficient to distinguish other observers fifteen yards distant, with a distinctness quite unexpected. At the same time the second-hand of a Waltham watch was easily seen. During the total phase the heavens exhibited a peculiar darkness.

I made no observations of the sun or its neighborhood until fifteen seconds after totality had commenced, my duties at the 6-inch CLARK equatorial necessitating individual attention for that period, after noting the approaching shadow. Mr. R. A. WALKER operated the slide and placed the plates in position, while I made the following exposures: Instantaneous, 1 second, 2 seconds, 4 seconds, 8 seconds, 16 seconds, 32 seconds, instantaneous, 1 second, 2 seconds. Ten plates in all.

The pictures recorded as instantaneous were probably exposed two tenths of a second. I deem it right to mention that in replacing the slide after the first exposure, I suspected the sun was displaced in the field, and at once requested Mr. Walker to verify the position in the finder. Upon receiving his assurance that the pointing was accurate, I exposed the remainder of the plates. The slight error in position on the plate, owing to the faulty pointing of the finder, must have been overlooked in the anxious moments of totality.

On turning to the eclipsed sun, during the exposure of the 8^s plate, *et seq.*, I at once remarked the brilliancy of the prominences and corona. The exceptional brightness of the former caused an apparent encroachment upon the black disc of the moon, giving it a serrated or coarsely indented aspect, which was especially remarked in the northeastern quadrant. The corona was extremely bright near the moon's limb, while the extensions in some directions probably exceeded two diameters of the moon's disc. No color was apparent at any time during the phenomenon, nor were rays or brushes of light visible to unassisted eyes.

I did not see any stars before totality, and had no opportunity of ascertaining whether the dark body of the moon could be seen projected on the background of the corona. As soon as circumstances permitted, I endeavored to sketch the corona, and had outlined the northwestern portion and the evident protuberances when totality ended. The corona and protuberances near the eastern limb were visible for five or six seconds after the reappearance of the sun. The corona presented a most delicate and complex structure of faint pencilings and curvatures, impossible to reproduce by hand, while a narrow rift of curious clearness separated the corona in a vertical direction.

Venus, *Jupiter*, and *Mercury* were very conspicuous during the total obscuration. *Mercury* continued visible for forty-five seconds subsequently to the total phase, *Jupiter* five minutes thirty-five seconds, and *Venus* forty-five minutes. The last contact was observed with the equatorial by Professor SCHAEBERLE; time by chronometer being $2^h\ 52^m\ 46^s$, and by myself by projecting the image of the finder, the time was noted as $2^h\ 52^m\ 45^s$.

WALTER F. GALE.

REPORT OF MR. WALKER.

I am not an astronomer, so you must not expect technical terms or phrases in this, my description of the most beautiful spectacle it has ever been my fortune to witness. The utter impossibility of pen, pencil, or brush to reproduce what Mr. AUBERTIN so very aptly called "God's Picture" impresses my mind very intensely, and makes still more evident (to my mind) the extremely short step science has advanced on the path at the end of which stands "Truth" beckoning with kindly hand to encourage the timid approach of man through the glare of light that surrounds His throne.

The eye of faith can plainly see
The hand that holds the light,
Guiding man on through the darkness,
Helping to do the "right."

The most striking feature of the total eclipse of the sun (in my opinion) was that the corona of light seen around the *very dark* body of the moon seemed to be the intercepted rays of light from the sun striking against—as it were—the back of the moon and flowing over it, thereby placing the moon inside a cone of light. The rays, so "splashing," being thrown out of their true course, caused a disturbance in the electric field or fluid (which pervades the globe "universe," as moisture does this our earth), thereby causing the corona of light, which, in color, in no way differed from the electric light as we use it.

Next as a spectacle comes the "shadow bands" thrown on the earth's surface, all around us, just at the beginning of totality. "Wonderful sight!" I can only liken it to the shadows of telegraph wires being racked about during an earthquake; in fact, to look at them produced the feeling that the earth, if not then shaking, would soon shake.

I think this phenomenon is ascribable to the rays of light which pass very near to the surface of the moon—passing through heat radiation of that body, the earth's surface being the background against which it is thrown. The same thing is to be seen on a pipe heated by steam and in the sunlight with some dark substance for a background. The twilight lines of light—and those only—just at the beginning of totality, having to pass through the radiation of heat on the surface of the moon (or better, on the edge of the sphere), become bent and distorted in their passage through the radiated heat, and so produce the shivering appearance of the "shadow bands" when they strike the earth.

I did not observe the planet *Mercury*, but *Venus* and *Jupiter* were very beautiful.

To the west of the observatory, and about 50° below the zenith, there was a very bright star to be seen; another at about 30° towards the south pole and 40° below the zenith, but not so bright as the first.

The light of the full moon is a warm, rosy light compared with that of the eclipsed sun; in my estimation the light was that of two full-moon power during totality.

I am so sorry about the telescope having gone wrong during operations, but am comforted with the fact that the nine times you made me photograph the moon for drill purposes—but under different circumstances—the whole of the nine images came out on the same plate, not showing even the faintest trace of a shake or move. I looked through the "finder" at the 8^s exposure, and everything seemed to be all right; had it been wrong, I question the wisdom of calling attention to it and thereby making bad worse.

I think, dear Professor, *you*, and science, through *you*, have a good deal to be thankful for with the results obtained, and beg to subscribe myself,

Yours most sincerely,
R. A. WALKER.

Mina Bronces, Jarillas, Carrizal,
April 19, 1893.

The observers at the DALLMEYER telescope conducted their work in a satisfactory manner. As this instrument was securely fastened to a fixed pier, the diurnal motion could not be allowed for. In order to get sharp definition and at the same time great extent of the corona, very short exposures with a large aperture were necessary. I feared, however, that with full aperture even the shortest time possible to give by hand might cause over-exposure for the inner corona. To guard, in a measure, against this, the following programme was carried out satisfactorily: The first four exposures corresponding to the times $0^s.2$, 1^s, 2^s, 4^s, were made with a diaphragm having an aperture of three inches inserted between the lenses. Mr. KING, who was at the objective end of the telescope, then drew out the diaphragm, leaving a full aperture for the remaining exposures, which were $0^s.2$, 1^s, 2^s, 4^s, $0^s.2$, 1^s, 2^s. Even the shortest exposure negative with the smaller stop gives the coronal extent to a distance of more than a solar diameter from the sun; so that a much smaller aperture than three inches could have been used to advantage for one of the series of exposures.

In so small a scale the motion of the image in 4^s causes but a slight distortion of the moon's outline, and the effect on the extent of the outer corona considered as an area is practically inappreciable.

The planets *Venus* and *Jupiter* are visible on all the plates taken with this instrument, the over-exposure in some cases being so great that the planetary disks are surrounded by the light ring due to reflection from the back surface of the plate.

I have assumed the times of exposure to be as follows:

Number of Plate.		Duration of Exposure.	Approximate Time after the Beginning of Totality.
1st Series.	1	¼^{s}	2^{s}
	2	1	14–15
	3	2	27–29
	4	4	41-45
2d Series.	5	¼	57
	6	1	69–70
	7	2	82–84
	8	4	96–100
3d Series.	9	¼	112
	10	1	124–125

With the 5 x 7 camera six exposures were made by Mr. Tirepegui, the durations being respectively 1^{s}, 2^{s}, 4^{s}, 8^{s}, 16^{s}, and 32^{s}.

Mr. Hole made eighteen exposures with the 4 x 5 camera, the exposure-times ranging between $\frac{1}{4}^{s}$ and 32^{s}.

Both of these cameras took in a large field of view, the outline of the mountain cutting off the eastern horizon being distinctly shown on these negatives.

I gave Mr. Martin, who was on Cerro Blanco with a 5 x 7 camera, instructions for observing the eclipse. He obtained four excellent negatives, two of which are now in possession of the Lick Observatory. I also sent Mr. Mirandi, of Carrizal Bajo, a box of 5 x 7 plates for use with his camera on Cerro Blanco. I have, however, obtained no information as to whether he was successful in his observations or not.

Naked-eye drawings, made by Mr. Aubertin and Lieutenants Brown, Bodger, and Wilson, and of Captain Parr, who was stationed at Merceditas, are kept at the Lick Observatory. As the photographs show greater extent to the corona than the drawings, only Mr. Aubertin's sketch is here reproduced.

REPORT OF MR. AUBERTIN.

The features of the total eclipse of April 16, 1893, chiefly struck me by comparison with those of the total eclipse of October, 1870, which I saw at Gibraltar. There the atmosphere was wild, charged, and threatening, and the period of total obscuration was much shorter, and, even so, not seen throughout.

Here the atmosphere at a height of 6,600 feet was absolutely pellucid; and the one grand, overwhelming figure was the symmetrical corona of a deep, circular margin extending all round into vallances or festoons of lovely texture.

There the corona was by no means so clear, but was confused by a long-spreading outside circle of penciled rays, reaching very far away. Here there was no pink coloring that I could discern, but only a short line of exceedingly bright excrescences on the northeast limb, though the rugged outline of the moon was attributed to an entire ring of inseparable excrescences.

There these were of a bright pink hue and considerable; being individually discernible. Here the moon appeared absolutely flat, and was of an intense blackness. There it appeared tinged, and looked completely spherical as it approached. Here the sun vexed the eye by extreme brightness up to four fifths of its obscuration, the whole disk of the moon being then traceable.

There it was easy to gaze throughout. The flash attending total obscuration was notable in both cases; as also the planets visible.

The pictures of these two phenomena present to my memory a most remarkable contrast. That of 1870 wild, boding, threatening, and compound in effects. This of 1893 exquisite in delicacy, and in purity and elegance complete. The actual darkness produced in 1870 was impressive; here it was of a mild type.

I did not measure the thermometer at Gibraltar; here it showed 60° F. at first contact, and gradually rose to 65°, *always in the sun.* Afterwards it began to decline gradually, and immediately after total obscuration, had fallen to 48°. After fourth contact it rose to 96°.

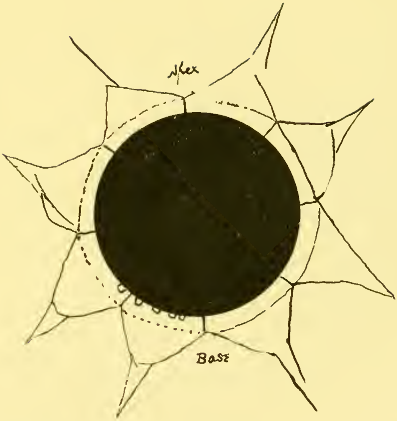

Plate V*a*. Naked-Eye View of the Corona.

The scenery all round, with the conical shadow approaching from the west over the closely grouped, brown, dry, russet-tinged mountains, added sublimity to the mighty phenomenon.

J. J. AUBERTIN.

Mina Bronces,
Tuesday, April 18, 1893.*

As the manuscript for the present volume was being set in type (February, 1895), I received a report from Mr. KING, of Carrizal Bajo, with an accompanying note, dated January 2, 1895, in which, among other matters, he says:

"This report is only a long letter to my sons in Scotland, which was read by some outside persons, who thought that it might be published, but it never was published nor offered for publishing. I send an abstract of it for you to use as you think fit. I have left out all descriptions of the apparatus, which will be much better done by yourself, though it was interesting to the boys."

CARRIZAL BAJO, May 5, 1893.

MY DEAR BOYS: The girls wrote to you about the eclipse observation at Merceditas by last mail. Professor TODD, of "Amherst," did not come at all. I received a letter from him just two weeks before the eclipse day, telling me that he had been unable to get up his party. We all felt sorry at this, for we had in a way got acquainted with him through our correspondence, and it was owing to his inquiries into cloud and climate conditions of this part of the country that the eclipse was professionally observed here at all.

Fortunately Professor SCHAEBERLE, of the Lick Observatory, came with much photographic apparatus. He made his observatory at Mina Bronces, and he worked very hard fitting up and getting ready his instruments for the great day, when we all helped him to expose the plates. The weather was just perfect on the 16th and the results entirely successful. I went up with mamma and the children to Merceditas on Friday, the 14th. I slept one night at Merceditas and rode up to Mina Bronces on Saturday morning. I had sent up my portable bed some days before, for I knew that there would be a great demand for beds. I arrived at eleven o'clock, and found the guests and principal mine employés assembled. After pleasant greetings and a wash, we had a pleasant breakfast. We then went up to the observatory and went through drill, for as the professor brought no assistants with him he had to depend on the assistants that he could pick up to help him to work the five photographic apparatus that he brought with him.

Two men were detailed to each camera: one to change the slides, and one to take off and put on the cap, and count the time of exposure. A man sat at a table with a chronometer; he had a stick, and he struck seconds on an empty box loud enough for us all to hear. The professor was very particular that the times of exposure be exact. He instructed us to say "zero" at the instant of taking off the cap. Then the next second beat was "one" and cap put on. The next plate was exposed two seconds; it was therefore timed "zero," "one," "two," and so on through the whole series. Mr. Bray and I took ten photos.

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* A very interesting and more extended description of this eclipse as seen with the naked eye, will be found in Mr. AUBERTIN'S little volume, entitled "BY ORDER OF THE SUN TO CHILE." Published by KEGAN PAUL, TRENCH, TRÜBNER & CO., London.

On Saturday night the professor put the plates in all the slides; he would not handle them in the day-time at all. He slept up beside his big telescope that night from one till daylight. We did not get asleep that Saturday night till very late, for people continued to come, and "shake downs" had to be made in every available room. The corral was so full of horses they could scarcely turn.

I awakened on Sunday morning just at dawn ; I got up to have a look at the weather; the stars were getting pale by the daylight, and it was a brilliant morning. I went back to bed, feeling that my part in the programme was safe—it was a clear day.

We all got up about six, and had coffee in detachments. The professor was down having coffee, in a fine humor, because the morning was fine. After coffee we went up to the instruments.

At 7^h 19^m A. M., local time, the first contact was seen to begin. And as the moon came down in front of the sun we could see the dark shadows on the hills opposite coming nearer and nearer. All the spectators were sent outside the ropes and absolute silence "*demanded*" from us by the professor. The black shadows on the hills came now quickly near till at last the sun appeared to give a mighty shiver and disappeared. The professor had told me not to look at the sun at all while the moon was coming on, for it unfitted the eyes for looking at the "corona." I was therefore standing with my back to the sun looking at the approaching dark conical shadow on the hills, when I saw the shiver that they call shadow bands shaking on the ground for about a second.

The professor shouted from his camera "expose." This was the signal that totality had begun and that we were to begin work. I had been seeing my shadow on the ground getting fainter, and when he shouted "expose," I still saw my shadow, and thought he had spoken too soon. I turned and looked for the sun and saw instead the beautiful "corona" giving as much light as four or six full moons. There was light enough for all outside work, even railway signaling or lawn tennis could have been carried on in the light. After that one look we all bent on to our work. There was a clatter of photographic slides and the tum, tum of second beater beating on his box, but no other sound. The spectators—about three hundred—stood silent, and after the first ejaculation as the "corona" burst into view, they neither spoke nor moved till totality was over. The "corona" is an irregular-shaped, white radiance, extending in places to about three diameters of the sun ; round the black—it is very black—moon, the radiance appears in bunches or bundles of rays, some shorter and some longer. Some of these bundles are radiant from the center, and some like tangents from the sun's side. The tips of these rays merge in sky; you cannot tell exactly where they end. As soon as totality was over, the professor shouted from his camera house, "Cover your slides"; so we rolled them up in the black velvet provided, and put the bundles in a light, tight box and sent the box down to the dark-room.

The slides of the large plates were put into their own box inside the camera, but the box even was not allowed to be in the light, and it was not carried down to the dark-room till night.

It was now breakfast time, eleven o'clock. It was a cheery breakfast; everything had gone well without a hitch. I think the room and table could seat fifteen. After the "Cazuela" I could hear six or eight all speaking at the same time, talking about the eclipse, telling their experiences, what they thought of the "corona," the "shadow bands," the cold, the light, the people, the planets, and everything.

The shadow bands were quite new to me. I had never heard of them, and no one there appeared to know what causes them, but just before totality there appeared on the ground, and I think also in the air, a succession of light and dark bands moving quickly about. The appearance of them was something like what one sees when passing a paling fence in a quickly moving railway train.

As I did not expect to see anything of the kind, the phenomenon was over before I could take a proper note of it. Many of the people did not notice these bands at all. I am confident that they did not last more than one second—possibly less. I did not notice them at the end of totality.

This phenomenon has evidently some connection with the instant that the edges of the sun and moon come in line with the observer's eye. I cannot think that the roughness of the moon's surface can be sufficient to cause the flickering that appears. I could not help thinking that the phenomenon might be caused by vibration; that the earth and moon—or at least one of them—do not sail through space smoothly, but that they tremble or vibrate as they go, and that at the instant of totality there is a clipping of light, which causes the dark and light bands.

It appears that the town of Carrizal Bajo was exactly in the line of limit of totality, the moon on one side just covering the sun, but nothing more, and at Carrizal Bajo the shadow band phenomenon was the feature of the eclipse. The bands were seen for a comparatively long time. An Italian shopkeeper and his wife were standing at their door watching the disappearing sun. When the bands appeared they had time to observe them, got frightened at them, and the wife fainted and had to be taken inside the house.

Mamma's washerwoman also said, after describing their appearance, "Casi desmayé con el susto."

They were seen by nearly every one, and lasted long enough to cause fear amongst the more ignorant.

I therefore think that the *limit* of totality is a better place to see the shadow bands than near its center. The edges of the sun and moon, and observer are longer in line; and possibly the lateral or side vibration of the moon is more effective in producing them.

After dinner SCHAEBERLE and WALKER went up to the Observatory and brought down the box of big plates to the dark-room. I also gave a hand, for the box was heavy.

The next morning, April 17th, we all went up to the Observatory and got photographed in position—every one at his camera. I do not know how this will turn out, but it cannot be like the real thing, owing to the absence of spectators.

The weather of the 16th had been finer than usual, with fine sunshine down to the coast; on the 17th, the weather was of the ordinary kind. "We looked down on a great white sea of mist or haze, with the tops of the hills sticking through." The visitors saw and remarked on the accuracy of the description in "Nature," of this white haze, the brilliant whiteness of the sun, and the indigo-like blue of the sky.

I did not wait for breakfast. I rode down with some others and arrived at Merceditas Station at eleven o'clock. I had breakfast there, and then we ran down home, where we arrived at five, highly delighted with our expedition.

Your loving father,

JOHN KING.

The last contact occurred $2^h\ 52^m\ 46^s$ chronometer time, the chronometer being fast $4^h\ 40^m\ 43^s$ on local sidereal time. Mr. GALE's time is one second earlier.

During a part of the interval between third and fourth contacts, the sun's crescent-shaped image was projected upon a white cardboard for the purpose of showing the awed natives this rare phenomenon.

Immediately after the third contact all the plate-holders were carefully protected from sunlight, and later on some were taken to the lower station, where enough were developed and examined to warrant my sending out an announcement of the complete success of the expedition. That same night Mr. WALKER and myself carried the large box containing the eight plates of 18 x 22 inches from the upper to the lower station—(this load was too precious to be intrusted to the back of any beast of burden going over the steep trail)—where I at once developed two of the plates. The next day, April 17, Mr. KING took a telegram for the Lick Observatory to the coast, wherein I announced the complete success of the observations and the apparent verification of the coronal theory by means of certain data given by the large-scale photographs.

As my whole time at Mina Bronces would henceforth be taken up with the photographic work of developing the fifty-two negatives obtained and making duplicate copies on glass, the instruments at the upper station were dismounted on Tuesday, April 18. Mr. GALE assisted me in this work until his departure, a day or two later.

As the cost of sending the cameras and frame-work of the 40-foot telescope back to California would be quite considerable, and as there was but little probability that the material would be used in the near future, I turned the whole structure over to Captain BRAY. It is proper to say here, that on account of the strong winds which occasionally came in gusts, it became necessary to nail the canvas to the wood-work in many places. The numerous holes produced in this way rendered the tube quite unfit for use on a future occasion.

The ten days following the eclipse were very busy ones, both day and night, in the dark-room. JOSÉ, now no longer needed at the deserted upper station, was made general assistant in the photographic department, and with the little scraps of blue paper, and an occasionally discarded landscape negative, he would amaze his fellow natives by his apparent knowledge of practical photography. It is safe to say that during the remainder of his days he will be regarded as the most learned native at Mina Bronces.

PRELIMINARY OBSERVATIONS FOR GEOGRAPHICAL POSITION.

As the geographical positions of the interior villages were only rudely known, it was necessary to have the means of determining latitudes and differential longitudes.

The most convenient and sufficiently accurate instruments for this purpose were the sextant and artificial horizon used in connection with a good chronometer. These were accordingly taken in my personal baggage, and were thus always available when wanted.

As already stated in the beginning of this report, it was impossible to make observations for time at Carrizal Bajo on the night of my arrival in that port. I did not wish to lose any time in the preliminary survey for a suitable station, and as Mr. KING assured me that terminals of the railroad could not be much out in longitude, I decided to start for the interior the very next day.

The chronometer was not kept running on the way down the coast. It was started before leaving Carrizal Bajo, and set to approximate Greenwich time by comparison with Captain JOHN THOMPSON's mean time Frodsham chronometer, on board the English bark "Iron Clad." In the following pages I have deemed it essential to print all the observations, for finding the geographical positions, in full; but in order to avoid inserting matter not absolutely necessary to the checking of my final values, the individual results are not given. Should, at any subsequent time, the occasion demand it, all the data for a complete re-reduction will be conveniently available. Occasional comparisons of my Elgin watch with the Negus sidereal chronometer are given as a check on the running of both timepieces while traveling from one station to another.

HARBOR OF CARRIZAL BAJO, Friday, March 10, 1893.
On board bark "Iron Clad."

Frodsham Chronometer No. 2392,	3^h 10^m $40^s.0$
Negus Chronometer No. 1720,	2 21 43 .0

The correction to the Frodsham chronometer in Greenwich mean solar time, as given to me by Captain THOMPSON, was

$$-3^m\ 40^s.$$

On shore:	Frodsham 2392,	3^h	16^m	$0^s.0$
	Elgin Watch,	10	27	51 .0
	Negus No. 1720,	2	54	0 .0
	Watch,	22	54	41 .2

Assuming that the correction of the Frodsham chronometer as given above is approximately correct, the correction of the Negus chronometer on Greenwich sidereal time was approximately

$$-40^s.$$

YERBA BUENA STATION, Friday, March 10, 1893.

Chronometer and Watch Comparisons.

Negus No. 1720,	11^h	28^m	$0^s.0$
Watch,	7	27	16 .5

The aneroid barometer at this time read 3,575 feet; Mr. KING's barometer registered 3,680 feet.

Sextant Observations of Regulus (α Leonis) for Latitude and Local Time, by Double Altitudes.

Observer, J. M. S.; Recorder, KING.

Chron. Time of Obs.			Sextant Reading.			Remarks.
13^h	7^m	55^s	85°	45′	20″	Low power.
13	17	32	88	42	10	Low power.
13	22	7	89	45	15	High power.
13	24	48	90	17	50	High power.
13	27	44	90	55	20	High power.

Index.

0°	0′	20″
0	0	25

13	35	24	92	24	35
13	38	4	92	52	20
13	42	10	93	35	30
13	46	38	94	20	0
13	50	35	94	55	0

Index.

0°	0′	10″
0	0	0
0	0	0
0	0	0

13	58	37	96	0	40
14	1	2	96	18	0
14	4	44	96	43	35
14	8	35	97	9	50

Index.
0° 0′ 0″
0 0 5
0 0 0
0 0 5

Chron. Time of Obs.			Sextant Reading.			Remarks.
14h	14m	15s	97°	40′	0″	
14	19	50	98	4	30	
14	24	47	98	25	50	
14	33	21	98	48	10	
14	44	20	98	59	20	
14	47	54	98	57	0	
14	50	35	98	54	0	

Index.
0° 0′ 10″

15	36	5	95	11	20
15	38	25	94	50	30

Index.
0° 0′ 15″
0 0 10

15	42	35	94	9	50
15	45	5	93	46	0
15	53	19	92	20	10
16	4	6	90	12	20
16	9	42	88	59	0
16	12	29	(88)	23	20

Index.
0° 0′ 10″

MERCEDITAS, Saturday, March 11, 1893.

Sextant Observations on Regulus for Local Time and Latitude.

Observer, J. M. S.; Recorder, KING.

Chronometer Time.			Sextant Reading.			Remarks.
11h	44m	28s	60°	33′	10″	
11	55	11	64	16	40	Aneroid reading,
12	7	27	68	24	10	2,895 feet.
12	10	29	69	21	23	

Index.
0° 0′ 10″
0 0 0
0 0 7

13	4	45	85	6	30
13	6	0	85	24	10
13	8	15	85	57	40
13	51	48	94	25	40
13	54	0	94	43	30
13	55	50	95	0	40

Index.
0° 0′ 5″
0 0 10

Chronometer Time.			Sextant Reading.		
14^h	28^m	30^s	97°	56′	30″
14	31	25	98	6	10
14	37	30	98	19	0
14	39	12	98	19	10
14	40	30	98	19	30
14	41	25	98	19	40
14	42	48	98	20	10
14	44	0	98	20	50
14	45	10	98	20	20
14	47	10	98	20	0
14	48	50	98	19	10
14	50	26	98	17	50

Index.

0°	0′	15″
0	0	10

15	38	57	94	17	30
15	41	20	93	54	0
15	47	18	92	59	10

Index.

0°	0′	15″
0	0	10

Remarks.

Chronometer and Watch Comparisons.

Chronometer, 15^h 28^m $0^s.0$
Watch, 11 22 39 .2
Thermometer, 57°.0 Fahr.
at 15^h 36^m chron. time.

Mina Bronces, Sunday, March 12, 1893.

Temperature at 7^h 20^m A. M., 54°.2 Fahr.

Sextant Observations on Regulus for Latitude and Local Time.

Observer, J. M. S.; Recorder, King.

Watch Time.			Sextant Reading.		
8^h	29^m	22^s	77°	59′	30″
8	30	28	78	36	40
8	33	0	79	2	20

Remarks.

As the chronometer was left at Merceditas, J. M. S.'s watch was used for observing the times.

Index.

0°	0′	10″
0	0	15
0	0	10
0	0	5

9	8	20	89	7	0
9	14	52	89	25	10
9	16	6	89	40	35

Index.

0°	0′	10″
0	0	15

9	48	0	95	3	40
9	49	18	95	15	0
9	52	50	95	39	30
9	54	22	95	50	50

Index.

0°	0′	5″
0	0	5

Watch Time.			Sextant Reading.			Remarks.
10h	10m	0s	97°	17′	10″	
10	12	5	97	26	20	
10	13	50	97	31	30	
10	16	20	97	40	30	
10	18	30	97	46	10	
10	20	45	97	52	0	
10	23	0	97	58	0	
10	26	20	98	3	50	
10	28	5	98	5	40	
10	29	25	98	7	30	
10	30	55	98	9	20	
10	33	40	98	10	10	
10	35	5	98	10	30	
10	36	10	98	10	40	
10	37	20	98	10	40	
10	39	10	98	9	50	

Index.		
0°	0′	15″
0	0	15
0	0	15

10	57	32	97	27	50
10	58	50	97	21	50
11	0	45	97	15	0

Index.		
0°	0′	15″
0	0	10

CARRIZAL BAJO, Monday, March 13, 1893.

Sextant Observations on Regulus for Latitude and Local Time.

Observer, J. M. S.; Recorder, KING.

Index.		
0°	0′	15″
0	0	15

Chronometer Time.			Sextant Reading.			Remarks.
13h	59m	42s	95°	29′	30″	
14	1	32	95	54	20	
14	2	53	96	3	50	
14	5	7	96	20	0	
14	9	26	96	39	40	

Index.		
0°	0′	20″
0	0	20

14	29	10	98	25	0
14	31	17	98	30	10
14	32	47	98	34	40
14	35	12	98	39	50

Index.		
0°	0′	20″
0	0	20
0	0	25
0	0	25

Chronometer Time.			Sextant Reading.			Remarks.
14h	41m	44s	98°	51′	0″	
14	43	32	98	52	0	
14	45	44	98	53	50	
14	48	23	98	53	40	
14	50	7	98	53	40	
14	51	41	98	52	40	
14	53	24	98	51	20	
14	55	36	98	50	0	

CARRIZAL BAJO, Tuesday, March 14, 1893.

Sextant Observations on Sun for Local Time and Latitude.

Observer, J. M. S.; Recorder, KING.

Chronometer Time.			Sextant Reading.			Remarks.	
1h	22m	3s.0	81°	1′	0″	Mercury vibrating	Upper limb.
1	25	21.0					Lower limb.
1	44	11.5	88	35	45	Upper limb.	
1	45	20.0	87	59	10	Lower limb.	
1	46	20.0	89	26	50	Upper limb.	
1	47	17.5	88	45	40	Lower limb.	
1	48	7.5	90	8	0	Upper limb.	
1	49	14.0	89	30	30	Lower limb.	

Index.		
359°	28′	20″
360	32	40
359	28	50
360	33	0

1	57	44.5	93	51	10
1	59	29.5	93	27	10
2	0	52.5	95	2	40
2	2	5.5	94	26	0
2	3	34.0	96	3	30
2	4	20.0	96	16	10

Chronometer and Watch Comparisons.

Chronometer,	(2h)	9m	0s
Watch,	21	53	45

6	36	20.5	98	4	50	Lower limb.
6	37	23.0	98	45	50	Upper limb.
6	40	14.5	96	39	0	Lower limb.
6	41	42.5	97	9	40	Upper limb.
6	42	54.0	95	39	50	Lower limb.
6	43	55.0	96	20	40	Upper limb.

Index.

360°	33′	20″
359	28	30
360	33	30
359	28	30

Chronometer Time.			Sextant Reading.			Remarks.
6^{h}	54^{m}	38.0^{s}	91°	13′	10″	Lower limb.
6	55	47.0	91	50	50	Upper limb.
6	56	51.0	90	0	40	Lower limb.
6	58	13.0	90	54	10	Upper limb.
6	59	51.0	89	11	30	Lower limb.
7	0	51.0	89	52	20	Upper limb.

Index.

359°	29′	10″
360	34	0
359	29	10
360	33	50

7	5	34.0	86	54	30	
7	7	24.0	87	19	0	
7	10	4.5	85	11	0	Lower limb.
7	10	48.0	85	56	50	Upper limb.
7	12	13.0	84	20	10	Lower limb.
7	13	25.0	84	55	46	Upper limb.

Index.

359°	29′	10″
360	33	30
359	29	10
360	33	20

Chronometer and Watch Comparisons.

Chronometer time,	7^{h}	18^{m}	$0^{s}.0$	7^{h}	19^{m}	$0^{s}.0$
Watch time,	3	1	52 .5	3	2	52 .2

MINA BRONCES, Wednesday, March 15, 1893.

Chronometer,	12^{h}	32^{m}	$0^{s}.0$
Watch,	8	10	59 .2

Sextant Observations on Regulus for Local Time and Latitude. (*Lower Station.*)

Observer, J. M. S.; Recorder, WALKER.

Chronometer Time.			Sextant Reading.			Remarks.
13^{h}	16^{m}	29^{s}	(88°	50′	10″)	
13	19	44	88	32	30	
13	21	44	88	58	0	
13	24	28	89	21	30	

Index.

359°	59′	10″	
359	59	30	Not very good observations.
359	59	40	

Chronometer Time.			Sextant Reading.			Remarks.
13^{h}	39^{m}	47^{s}	92°	26′	0″	
13	42	26	92	52	20	
13	43	56	93	7	30	
13	45	35	93	23	20	

Index.

359° 59′ 40″
359 59 50
359 59 50

14	12	58	96	46	50
14	17	5	97	6	0
14	20	48	97	21	50
14	26	3	97	40	50
14	30	38	97	53	40
14	35	46	98	4	10

Index.

359° 59′ 55″
360 0 0
360 0 0

14	39	4	98	7	0
14	41	5	98	8	30
14	42	16	98	9	10
14	43	44	98	9	10
14	45	12	98	9	10
14	47	22	98	8	30
14	49	23	98	7	20
14	54	36	98	2	10
15	11	23	97	6	0

Index.

360° 0′ 0″
360 0 0

15	42	47	93	23	40
15	47	31	92	39	0
15	50	3	92	12	30
15	51	51	91	49	10
16	4	43	89	22	0
16	8	40	88	32	30
16	11	45	87	50	10

Index.

0° 0′ 5″
0 0 0

Chronometer and Watch Comparisons.

Chronometer,	16^{h}	24^{m}	$0^{s}.0$
Watch,	12	2	20 .5

MINA BRONCES, Thursday, March 16, 1893.

8:00 A. M.—Lower Station aneroid, 6,170 feet.
8:20 A. M.—Upper Station aneroid, 6,415 feet.

Sextant Observations on Sun—A. M. observations.

Observer and Recorder, J. M. S.

Chronometer Time.			Sextant Reading.			Remarks.	
0h	46m	50.5s	62°	29′	20″	Art. horizon	Direct.
0	49	26.5					Reversed.
0	51	38.5	64	30	0		R.
0	54	13.0					R.
0	56	27.0	66	29	0		R.
0	58	57.0					D.
1	1	15.5	68	29	40		D.
1	3	52.0					R.
1	6	7.5	70	29	20		D.
1	8	43.0					

Index.		
360°	32′	20″
359	27	40
360	32	20
359	27	50

Chronometer,	1h	21m	0s.0	Upper Station.
Watch,	20	57	52.2	
Chronometer,	1	56	0.0	Lower Station.
Watch,	21	32	45.3	Aneroid, 6,155 feet.

At 10h 17m A. M. watch was accidentally struck; still running, the first of the two following comparisons was at once made:

Chronometer,	2h	43m	0s.0	
Watch,	22	19	37.5	
Chronometer,	5	40	0.0	
Watch,	1	16	7.8	Lower Station.

Aneroid, 6,160.

Upper Station, aneroid 6,415.

P. M. Observations on Sun.

Observer and Recorder, J. M. S.

Index.		
360°	32′	20″
359	28	0
360	32	30
359	28	10

Chronometer Time.	Sextant Reading.	Remarks.
6^h 45^m 53.0^s	94° 29′ 30″	Thermometer at 2 P. M., 67°.5 Fahr.
6 48 47.0		
7 27 29.0	78 29 20	
7 30 8.0		
7 42 20.5	72 30 0	
7 44 54.0		
7 47 12.5	70 29 40	
7 49 48.5		
7 52 3.5	68 29 30	
7 54 38.5		
7 56 53.0	66 29 10	
7 59 28.0		
8 1 43.0	64 29 20	
8 4 13.0		
8 6 31.0	62 28 50	
8 9 4.0		

Index.

360° 32′ 0″

359 27 50

Chronometer,	8^h	23^m	0^s
Watch,	3	58	40

A provisional reduction of all the preceding observations, which I finished on March 16, gave the *approximate* coördinates of the eclipse station, which I used in computing the local times of contacts of the solar and lunar disks on April 16. These provisional coördinates were:

Latitude, —28° 27′
Longitude, 4^h 41^m 16^s west from Greenwich.

The computed times of second and third contacts, using the above coördinates, I found to be:

$$\text{April 16, 1893,}\quad \left.\begin{array}{ll}\text{II,} & 1^h\ 2^m.316 \\ \text{III,} & 1\ \ 5\ .195\end{array}\right\}\ \text{Greenwich mean time.}$$

And the resulting hour-angle (and declination) of the sun at the middle time of the eclipse:

Hour-angle, 22^h 22^m 49^s
Declination, +10° 19′ 12″

These values were used in orienting the position of the 40-foot telescope, the erection of which was commenced on March 20, and described in the foregoing pages.

Mina Bronces, Thursday, March 17, 1893.

At 8 A. M., Therm., 59°.8 } Lower Station.
Bar., $23^{in}.71$

Upper Station.

A. M. Sextant Observations on Sun.

Chronometer Time.			Sextant Reading.			Remarks.
2^{h}	13^{m}	35.5^{s}	95°	0′	0″	
2	16	35.0				
2	19	10.0	96	59	20	
2	22	10.0	97	0	30	
2	30	31.0	101	0	0	
2	33	38.0				

Index.		
360°	31′	0″
359	27	40
360	31	30
359	27	50
360	32	0
359	27	30

Chronometer,	3^{h}	30^{m}	$0^{s}.0$
Watch,	11	2	31 .2

P. M. Observations.

Index.		
360°	31′	20″
359	27	30
359	27	20
360	31	30

6^{h}	29^{m}	36.5^{s}	100°	59′	30″	At 2 P. M. clouds in south-west, up to altitude of 10°.
6	32	43.0				
6	35	22.5	99	0	0	
6	38	25.5				
6	41	8.0	96	59	40	
6	44	6.5				
6	46	41.0	94	59	20	
6	49	36.0				

Index.		
360°	32′	50″
359	27	40
360	32	20
359	27	50

Chronometer,	9^{h}	52^{m}	$0^{s}.0$
Watch,	5	23	26 .5

MINA BRONCES, Monday, March 20, 1893.

At 7:50 A. M., Bar., $23^{in}.70$ } Lower Station.
Ther., 58°.0 }

Upper Station.

Sextant Observations of Regulus.

Observer, J. M. S.; Recorder, WALKER.

Chronometer Time.			Sextant Reading.			Remarks.
12^h	46^m	5^s	80°	12′	0″	
12	50	8	81	18	10	
12	53	30	82	13	0	
12	55	38	82	46	30	

Index.

359°	59′	50″
359	59	50
359	59	55

Chronometer, 13^h 3^m 0^s
Watch, 8 21 56.5

14	13	5	96	46	50
14	33	17	97	58	0
14	37	0	98	4	20
14	38	58	98	6	10
14	41	6	98	7	20
14	44	6	98	9	50
14	45	48	98	8	20
14	50	12	98	6	30
14	51	46	98	4	40

Index.

0°	0′	10″
0	0	10
0	0	10

MINA BRONCES, Monday, March 27, 1893.

Sextant Observations on Regulus for Latitude.

Observer, J. M. S.; Recorder, WALKER.

Chronometer Time.			Sextant Reading.			Remarks.
13^h	46^m	18^s	93°	33′	10″	
13	48	12	93	50?	0	
13	50	5	94	7	20	
13	53	9	94	33	30	
13	55	25	94	51	50	

Index.

0°	0′	30″
0	0	20
0	0	20
0	0	25

14	1	19	95	34	20	
14	2	42	95	46	0	
14	4	38	96	0	0	The minute is either 6 or 7;
14	5	53	96	(7)?	0	both figures are recorded,
14	7	34	96	16	40	one over the other.

	Index.	
0°	0′	20″
0	0	30

Chronometer Time.			Sextant Reading.			Remarks.
14^{h}	39^{m}	37^{s}	98°	9′	0″	
14	41	58	98	9	10	
14	42	26	98	9	10	
14	44	11	98	9	40	
14	45	48	98	9	10	
14	47	20	98	8	10	
14	48	53	98	7	10	

MINA BRONCES, Tuesday, March 28, 1893.

Chronometer,	9^{h}	49^{m}	0^{s}
Watch,	4	41	8.5

MINA BRONCES, Wednesday, March 29, 1893.

Sextant Observations on Regulus for Time and Latitude.

Observer and Recorder, J. M. S.

Chronometer Time.			Sextant Reading.			Remarks.
13^{h}	6^{m}	10^{s}	85°	30′	0″	
13	10	16	86	30	0	
13	14	41	87	30	0	
13	19	13	88	30	0	

	Index.	
0°	0′	0″
0	0	0

14	37	17	98	6	40
14	40	0	98	8	40
14	42	50	98	9	30
14	44	50	98	9	30
14	47	20	98	9	0

	Index.		
0°	0′	0″	Index correction for 14^{h} 50^{m}
0	0	10	
0	0	0	Index correction for 16^{h} 0^{m}
0	0	10	

16	3	55	89	30	0
16	8	35	88	30	0
16	13	8	87	30	0
16	17	30	86	30	0
16	21	39	85	30	0

	Index.	
0°	0′	10″
0	0	0

To avoid as far as possible the unknown instrumental errors, and also errors of refraction, the sextant was often set to a given reading (usually a whole or half degree mark), and the coincidence, brought about by the earth's rotation, watched for. The sextant was then set to the same readings, but in the reverse order, for the post-meridian observations of the same object.

MINA BRONCES, Thursday, March 30, 1893.

Chronometer,	8^h	45^m	0^s
Watch,	3	29	23

MINA BRONCES, Friday, March 31, 1893.

Chronometer,	8^h	24^m	0^s
Watch,	2	48	40.5

The watch stopped this A. M., presumably during the horseback ride to and from the upper station. Watch set forward 16^m.

Chronometer,	8^h	48^m	0^s
Watch,	3	28	37.5

MINA BRONCES, Saturday, April 1, 1893.

Chronometer,	6^h	50^m	0^s
Watch,	1	26	54

Sextant Observations on Regulus.

Observer and Recorder, J. M. S.

Chronometer Time.			Sextant Reading.			Remarks.
13^h	20^m	56^s	88°	53′	30″	
13	26	19	90	0	0	
13	28	52	90	30	0	

Index.

0° 0′ 10″
0 0 20

15	58	46	90	30	0	Windy.
16	1	14.0	90	0	0	
16	6	37.0	88	53	30	

Index.

0° 0′ 20″
0 0 20

MINA BRONCES, Thursday, April 6, 1893.

Sextant Observations on Regulus.

Observer and Recorder, J. M. S.

Chronometer Time.			Sextant Reading.			Remarks.
13^h	26^m	15^s	90°	1′	20″	
13	30	29	90	50	0	
13	35	57	91	52	0	
(13	50	39)	94	16	0	

Index.

0° 0′ 0″ Index for 13^h 52^m

Chronometer Time.			Sextant Reading.			Remarks.
15^{h}	36^{m}	28^{s}	94°	16′	0″	
15	51	16	91	52		

Index.
0° 0′ 0″

15	56	50	90	50	0	
16	0	53	90	1	20	

Mina Bronces, Saturday, April 15, 1893.

Sextant Observations on Sun for Time.

Observer and Recorder, J. M. S.

Chronometer Time.			Sextant Reading.			Remarks.
4^{h}	22^{m}	37.0^{s}	86°	0′	0″	
4	26	26.0				
4	29	57.0	88	0	0	
4	33	59.5				
4	37	35.0	92	0	0	
4	47	46.0				

Index.
359° 27′ 10″
360 32 10

In the afternoon it was cloudy, so that no corresponding series of P. M. observations could be obtained.

Mina Bronces, Monday, April 17, 1893.

Sextant Observations on α Virginis for Time.

Chronometer Time.			Sextant Reading.			Remarks.
13^{h}	34^{m}	31.5^{s}	77°	38′	30″	
13	37	52.0	79	3	30	
13	41	21.0	80	34	0	
13	43	23.5	81	28	0	

Index.
0° 1′ 0″
0 1 0

Some of the volunteer observers had been making experimental observations with the sextant, which accounts for the large index correction.

Mina Bronces (Lower Station), Friday, April 28, 1893.

Sextant Observations on Sun for Time.

Chronometer Time.			Sextant Reading.			Remarks.
4^{h}	15^{m}	23^{s}	62°	3′	30″	Roof Direct. Reversed.
4	18	28				
4	20	57	63	55	0	R
4	22	40	63	24	40	D
4	24	1	64	53	50	D
4	25	30	64	29	40	R. Mercury vibrating.

Chronometer Time.	Sextant Reading.	Remarks.
4^{h} 28^{m} 41^{s}	66° 23′ 0″	
4 30 29	65 54 50	Mercury vibrating.

Index.	Remarks.
359° 27′ 40″	
360 31 20	Bar., 23.430 in. = 6,480 ft.
360 31 10	Ther., 54° Fahr., at about 10 A. M.
359 27 30	

P. M. Observations on Sun.

Chronometer Time.	Sextant Reading.	Remarks.
11^{h} 7^{m} 47.5^{s}	34° 37′ 30″	
11 9 20.0	35 4 30	Bar., 6,475 ft.
11 12 0.0	32 58 50	Ther., 54.0° Fahr.
11 14 31.0	33 3 30	
11 15 40.0	31 33 50	
11 16 46.0	32 11 20	

Index.
359° 27′ 10″
360 30 30
359 27 20
360 31 0

As some of the earlier and these last observations were made at the lower station, it became necessary to know with sufficient accuracy the distance, difference of altitude, and the azimuth of the lower station referred to the upper station, in order that all the values for local position might be referred to the upper station.

With the assistance of José, the linear distance, in a vertical plane, along the earth's surface, was measured with the 50-foot steel tapeline. The general inclination of the inclined portion of the line, as well as the azimuth, was determined with the sextant. Two sets of observations were made; one going from the lower to the upper station, and the other retracing the line from the upper to the lower station. The mean values of the two sets of measures are as follows:

From the lower station (which is at a point on a brick wall about three feet above the ground, directly in front of the main administration building), a horizontal distance of 350 feet; then on a line inclined 21° to the horizontal, a distance of 750 feet; then, again on a horizontal line, a distance of 372 feet.

The horizontal distance between the two stations and the difference of altitude are therefore—

Horizontal distance,	1,422 feet.
Difference of elevation,	269 feet.

Practically the same difference of elevation is given by the aneroid readings.

Neither station can be seen from the other. As viewed from the upper station the azimuth of the line to the lower station is approximately north 15° west.

The approximate difference of longitude and latitude, with sufficient accuracy for all practical purposes, is therefore—

Difference in longitude, 368 feet $= 0^s.3$
Difference in latitude, 1374 feet $\doteq 14''$

The corrections to be applied to all observations made at the lower station to reduce them to the upper station are therefore—

In time, $+ 0^s.3$
In latitude, $- 14''$
In altitude, + 269 feet.

On Saturday, April 28, I left Mina Bronces, early in the morning, for Merceditas and Carrizal Bajo. At both of the last-mentioned places sextant observations were made to secure additional data for a still more accurate value of the longitude of the observing station.

MERCEDITAS, Saturday, April 29, 1893.

NOTE.—The point of observation is just in front of the station house and about five feet (as I recollect it) from the railroad track.

Observations on the Sun for Local Time.

Observer and Recorder, J. M. S.

Chronometer Time.			Sextant Reading.			Remarks.
5^h	50^m	25^s	86°	22′	50″	
5	53	32	85	57	0	
5	56	3	87	27	40	
5	58	21	86	50	50	
6	0	24	88	14	50	
6	1	48	87	26	10	

Index.		
359°	27′	20″
360	31	10
360	31	20
359	27	50

Chronometer Time.			Sextant Reading.			Remarks.
6h	52m	5s	94°	3′	30″	
6	55	3	93	7	30	
6	(57)	6	93	11	0	
6	59	0	94	18	10	

Index.

360°	31′	40″	Thermometer, 65°.0 Fahr.
359	28	0	

7	7	40	94	27	50	Upper limb.
7	10	30	94	27	50	Upper limb.
7	13	10	94	27	20	Upper limb.
7	44	2	91	49	10	Lower limb.
7	46	(21)	92	38	30	Upper limb.
7	48	34	92	25	40	Upper limb.
8	27	23	85	33	50	
8	29	7	86	15	40	
8	30	45	84	53	20	
8	32	6	85	41	0	

Index.

359°	27′	40″
360	31	20
360	31	10
359	27	50

CARRIZAL BAJO, Saturday, April 29, 1893.

NOTE.—The point of observation is near the center of the plot of ground containing Mr. KING's residence. (Perhaps 30 feet from the house on the side which is towards the railroad, probably nearly east.)

Sextant Observations on Arcturus and Canopus.

Observer, J. M. S.; Recorder, KING.

Chronometer Time.			Sextant Reading.			Remarks.
Arcturus.						
17h	5m	18s	70°	44′	30″	
17	9	8	71	38	20	
17	10	44	72	1	20	
17	13	7	72	32	30	
Canopus.						
17	20	22	39	47	10	
17	22	20	39	12	20	
17	23	40	38	50	40	

Index.

0°	0′	50″	Aneroid, 29in.81.
0	0	40	Thermometer, 65°.0 Fahr.
0	0	50	

With this day's work the astronomical observations having to do directly with the eclipse came to a close.

The sextant and its subsidiary apparatus, and the chronometer were accordingly carefully packed with the other instruments, for shipment to the Lick Observatory.

The aneroid, being a small pocket instrument, was in almost constant use during the remainder of the journey home.

Resulting Values for the Geographical Positions of Carrizal Bajo, Yerba Buena, Merceditas, and Mina Bronces.

In the reduction of the foregoing observations, interpolated values in the following auxiliary table were used in computing the refraction at the various stations. (See Bessel's Tables; factor depending upon the aneroid readings.)

Aneroid Reading. Altitude, in Feet.	Log. B.
2,275	—0.0319
2,760	—0.0399
3,240	—0.0479
3,735	—0.0561
4,235	—0.0645
4,755	—0.0730
5,275	—0.0816
5,815	—0.0903
6,360	—0.0992
6,910	—0.1082

The chronometer corrections on the local sidereal time at the several stations follow here:

Table of Values of the Chronometer Correction.

Place of Observation.	Date. Chronometer Time of Epoch for Rate.	Chronometer Correction on Local Sidereal Time.	Observations Corrected for Rate and Referred to Epoch March 14^{d} 4^{h}.4.	Observations Corrected for Mean Rate and Adopted Longitudes, Referred to Carrizal Bajo Epoch March 14^{d} 4^{h}.4.
Yerba Buena	Mar. 10, 14^{h}.7	—4^{h} 41^{m} 27^{s}.8	—4^{h} 41^{m} 23^{s}.0	—4^{h} 44^{m} 59^{s}.1
Merceditas	Mar. 11, 14 .7	42 10 .2	42 6 .8	44 61 .6
Carrizal Bajo	Mar. 14, 4 .4	44 59 .1	44 59 .1	44 59 .1
Mina Bronces	Mar. 15, 14 .7	41 30 .9	41 32 .8	44 58 .1
Mina Bronces	Mar. 16, 4 .5	41 31 .2	41 33 .8	44 59 .1
Mina Bronces	Mar. 17, 4 .5	41 31 .7	41 35 .7	44 61 .0
Mina Bronces	Mar. 29, 14 .7	41 12 .2	41 32 .9	44 58 .2
Mina Bronces	Apr. 1, 14 .7	41 5 .6	41 30 .2	44 55 .5
Mina Bronces	Apr. 6, 14 .7	40 54 .2	41 25 .6	44 50 .9
Mina Bronces	Apr. 15, 4 .5	40 45 .4	41 28 .3	44 53 .6
Mina Bronces	Apr. 17, 13 .6	40 41 .3	41 27 .4	44 52 .7
Mina Bronces	Apr. 28, 11 .2	40 34 .3	41 34 .6	44 59 .9
Merceditas	Apr. 29, 7 .0	41 1 .1	42 2 .9	44 57 .7
Carrizal Bajo	Apr. 29, 17 .3	41 56 .6	44 59 .0	44 59 .0

As all the observations for longitude are to be referred to Carrizal Bajo, and as the conditions for getting accurate values of the chronometer correction were good both on March 14 and April 29, a mean value of the chronometer rate was at once obtained without involving any error in the assumed longitude. Assuming that there was no tripping of the timepiece between these two dates, the value of the mean daily losing rate of the chronometer is found to be

$$1^{s}.34.$$

To obtain a general oversight of the actual performance of the chronometer, this rate has been applied to each chronometer correction, giving the results (found in the fourth column) which would have been obtained had the chronometer possessed no rate either before or after March 14, $4^{h}.4$. A fifth column has also been added, giving hypothetical values of the chronometer correction on the assumption that all the observations were made at Carrizal Bajo. That is, the adopted differences of longitude have been applied to the values given in the fourth column to obtain the figures given in the fifth column.

The rate of the chronometer during the time it was in use at Mina Bronces was not uniform, as is well shown in the third, fourth, and fifth columns. From March 15 to 17 the chronometer (taken back and forth, from the upper to the lower station, daily) was slightly gaining. After this time it was kept inside of one of the large empty instrument boxes at the upper station, when not in use, until the day after the eclipse, when it was taken to the lower station and kept undisturbed (except for the daily winding) until about the time of my departure from Mina Bronces. During the time it was in the box at the upper station the mean daily rate was about $1^{s}.6$ losing. In my room from April 17 to 28 the rate was nearly a whole second smaller.

There are reasons to suspect that an appreciable portion of this last result may be due to a deviation of the plumb-line at the lower station, where the last observation for time was made. As has already been stated, the mine is on the *west* slope of the Cerro Cobre Mountain; the local zenith would therefore lie on the west side of the astronomical zenith; the observed chronometer correction would therefore be greater than the true correction.

For determining the difference of longitude between Carrizal Bajo and the stations Yerba Buena, Merceditas, and Mina Bronces, it is evident that only those observations should be used, in each case, which are separated by the least interval of time from those made at Carrizal Bajo. From the fourth column of the last table we obtain for the March values:

Longitude of Carrizal Bajo — Longitude of Yerba Buena, $= +0^h\ 3^m\ 36^s.1$
Longitude of Carrizal Bajo — Longitude of Merceditas, $= +0\ \ 2\ \ 52.3$
Longitude of Carrizal Bajo — Longitude of Mina Bronces, $= +0\ \ 3\ \ 26.3$

The April values are:

Longitude of Carrizal Bajo — Longitude of Merceditas, $= +0^h\ 2^m\ 56^s.1$
Longitude of Carrizal Bajo — Longitude of Mina Bronces, $= +0\ \ 3\ \ 24.4$

In March an interval of nearly three days elapsed between the time determinations at Merceditas and Carrizal Bajo. I have consequently given the resulting values for the difference of longitude only one half the weight assigned to the corresponding difference in April. For Mina Bronces a simple mean of the March and April values has been used.

The adopted values of the difference of longitude are:

Carrizal Bajo — Mina Bronces, $= +0^h\ 3^m\ 25^s.3$
Carrizal Bajo — Merceditas, $= +0\ \ 2\ \ 54.8$

LATITUDE DETERMINATIONS.

The latitudes of the stations were determined from the observations made on both sides of the meridian, and near the time of culmination of the object observed. The results for the different dates are given in the following table:

UNCORRECTED RESULTS OF THE DETERMINATIONS OF LATITUDE.

Place.	Date.	Latitude.	Weight.
Yerba Buena	March 10	—28° 2′ 30″	1
Merceditas	March 11	—28 21 13	1
Mina Bronces (Lower Sta. + 14″)	March 12	—28 26 14	1
Carrizal Bajo (Mr. KING's home)	March 13	—28 4 43	1
Mina Bronces (Lower Sta. + 14″)	March 15	—28 26 50	1
Mina Bronces	March 20	—28 26 48	1
Mina Bronces	March 27	—28 26 48	1
Mina Bronces	March 29	—28 26 29	1
Merceditas (Sun)	April 29	—28 21 21	1

In several instances a number of measures were omitted in order to have a more uniform and symmetrical distribution of the observations with reference to the meridian. I am unable to account satisfactorily for the rather small value of the latitude of Mina Bronces, given by the observations of March 21, and for that reason have given it full weight. My watch was used for recording the times of observations, the chronometer being at Merceditas, but no sensible error could have resulted from this cause. The readings, when compared with those of the other dates, plainly show that the whole difference is to be found in the measured angle.

A sextant specially ordered to be constructed for the expedition did not arrive in time, so the one used was borrowed from the UNIVERSITY OF CALIFORNIA. To make sure that no large instrumental errors of graduation or eccentricity affected the latitudes, I recently determined the values of a number of angular sextant intervals measured directly by the method which I first published in 1888. (See Astr. Nach., No. 2832.)

The Lick Observatory meridian circle, of course, gave the measured angles to a superfluous degree of accuracy. In making the measures the diaphragm of the micrometer eye-piece was shifted until the declination micrometer wire, set to the reading on the nadir, passed exactly through the center of the diaphragm.

To render insensible any small errors—resulting from the fact that two different eccentric areas of the meridian circle objective are used, and that the diaphragm is slightly beyond the focal plane—the index-correction of the sextant was determined by measuring (precisely as in case of the sun) twice the vertical diameter of the sharply defined diaphragm as seen through the meridian circle objective; the light of the sky gives excellent illumination for making the measures. It should be mentioned that the micrometer eye-piece must be removed during all the sextant measures, so that only the diaphragm is between the meridian circle objective and the sky.

All the coincidences of the diaphragm images, in measuring the several angles, were deduced from the measures of twice the angular diameter of the diaphragm, which, seen through the objective, subtended an angle of 13′.

Only the sextant arc from 40° to 100° was investigated—to cover the measures included in this report; the results are given in the following table:

RESULTS OF THE INVESTIGATION OF THE SEXTANT.

(Brunton, 3. America Sq^re^, London.)

Meridian Circle. (Double Depression.)			Sextant Reading.			Correction to Sextant.		
40°	0′	0″	39°	59′	54″	+0°	0′	6″
60	0	0	59	59	49	+0	0	11
80	0	0	79	58	49	+0	1	11
85	0	0	84	58	39	+0	1	21
90	0	0	89	58	59	+0	1	1
95	0	0	94	58	54	+0	1	6
100	0	0	99	58	49	+0	1	11

In reducing the observations for time no eccentricity error was employed, for while the two sets of chronometer corrections corresponding to the observations on opposite sides of the meridian invariably indicated small errors in the angles, the observations were so selected and reduced as to eliminate the effect of the instrumental errors. On April 15, however, only A. M. observations were secured, and on April 17 the observations also refer to the same side of the meridian ; the chronometer corrections for those two dates, allowing for the eccentricity, would therefore be :

$$\text{April 15, } 4^h.5, \; -4^h\ 40^m\ 41^s.2$$
$$\text{April 17, } 13\ .6, \; -4\ \ 40\ \ 38\ .8$$

The chronometer correction for the times of the two contacts on April 16 was therefore

$$-4^h\ 40^m\ 40^s$$

Nearly all the sextant readings used for finding the latitudes are included between the limits 80° and 100°. The last column of the above table shows that between these limits the corrections to the sextant readings can be given the value

$$+\ 70''$$

All the latitudes given on page 75 are therefore to be numerically diminished by 35″.

Collecting together all the observed results for the geographical positions, and using the value

$$4^h\ 44^m\ 47^s.8^*$$

as the longitude of Carrizal Bajo west of Greenwich, the adopted values given below are obtained:

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* This value is deduced from the data given in the "Connaissance des Temps."

ADOPTED GEOGRAPHICAL POSITIONS.

Place.	Longitude.	Latitude.	Elevation—In Feet.
Carrizal Bajo	$4^{h}\ 44^{m}\ 47^{s}.8$	—28° 4′ 8″	20±
Mina Bronces (Upper Sta.)	4 41 22.5	—28 26 3	6,600
Merceditas	4 41 53.0	—28 20 42	2,900
Yerba Buena	4 41 11.7	—28 1 55	3,700

Mr. KING could give me no definite information as to the exact location of the point to which the given longitude of Carrizal Bajo refers. He thought, however, it could not be far distant from the place of observation at his residence.

WEATHER CONDITIONS AT MINA BRONCES.

The climatic conditions prevailing at this station during my stay were remarkably uniform. I believe the thermometer never rose above 70°, nor fell below 50° Fahr. The mornings were usually without wind, but every afternoon a fresh breeze would blow from the northwest.

On exceptional occasions, the sky would become overcast—less frequently, however, before than after the eclipse.

It was intended, if possible, to carry on a series of meteorological observations, but my time was so much occupied with far more important matters, that only an occasional record of the weather conditions was jotted down. Indeed, the variation from day to day was almost imperceptible, so that often only the exceptional would attract the attention sufficiently to cause me to make a note of the fact.

Following are some meteorological notes. Unless stated to the contrary, the weather was clear (viz., no clouds overhead) on every date and intervening dates. The barometer readings refer to the lower station :

March 12. 7:20 A. M., ther. 54°.2 Fahr.
16. 8:30 A. M., clouds in the east; alt. 10°. 2:00 P. M., ther. 67°.5.
17. 8:00 A. M., ther. 59°.8; bar. 23.71. 2:00 P. M., clouds in southwest; alt. 10°.
18. 8:00 A. M., ther. 58°.0; bar. 23.66.
20. 7:50 A. M., ther. 58°.0; bar. 23.70.
21. 10:00 P. M., sky nearly covered with clouds.
22. 9:00 P. M., ther. 59°.0; clouds in some parts of the sky all evening.
24. 8:00 A. M., ther. 56°.5. Nearly every afternoon storm clouds gather over the Cordilleras, and occasionally cover the sky overhead; the wind starts up at about the same time, blowing from the west.

March 27. Clouds in various parts of the sky. Thunder in the afternoon, but confined to the Cordilleras; this A. M. it was clear as usual.

31. To-day the clouds (fog) came within two miles of the station, covering everything terrestrial to the west of us. At Merceditas, the sky must have been wholly obscured. At $10^h\ 11^m\ 30^s$, local mean time, a very bright meteor explosion, considerably above a line joining *Pollux* with *Capella*, and nearer to the latter, lit up the landscape, even in the presence of the full moon.

April 9. Cloudy in the evening.

10. Cloudy all day and night.

12. 8:00 A. M., ther. 55°.0. 3:20 P. M., ther. 56°.3.

15. Cloudy in the afternoon.

16. 6:00 A. M., ther. 50°.0. 7:30 A. M., 55°.0. 8:00 A. M., 55°.0.

After the last date recorded above no further attention was given to the weather, except to notice that the sky was more frequently overcast, and also that on one or two occasions it rained quite hard. On another occasion a squall-like movement of the atmosphere came upon us so suddenly that a number of eclipse negatives in the process of drying, after development, were covered with a coating of gritty dust before they could be protected from this unexpected foe. A careful re-washing, assisted by a camel's-hair brush, finally removed this undesirable layer. The rainy season set in soon after my departure.

Miscellaneous Photographic Observations.

Although some of the observations recorded under this head have not yet been reduced, it has been thought well to print the records for more convenient use in working up the data and also to guard against a possible loss of the original notes.

The negatives were all developed at Mina Bronces and are now at the Lick Observatory.

The miscellaneous photographic work consisted in—

(*A*) Exposures for focus.

(*B*) Exposures for finding the photographic atmospheric absorption.

(*C*) Short exposures for showing the brighter stars in the southern sky, and long exposures for obtaining good representations of the region about η *Argus* and the *Greater Magellenic Cloud.*

(*D*) Terrestrial views, experimental and otherwise.

(*A*) Numerous experimental plates were exposed at the Lick Observatory before my departure for Chile, but aside from the satisfactory evidence they give as to the performance of the lenses, no further use will be made of these nor of those experimented with at Mina Bronces. It need only be mentioned that all the telescopes, from the 40-foot down to the 4 x 5 camera, were again carefully tested for photographic focus at Mina Bronces.

(*B*) My previous work in this line (absorption) made it clear that the best results can only be obtained when a very bright star is available on which to make the exposures. It so happened that the brightest star in the whole heavens was particularly well situated to obtain a great range in zenith distance. Shortly after evening twilight *Sirius* was only a little to the west of the meridian, and observations were continued until the star was occulted by a mountain ridge (ten miles distant), behind which it disappeared. This photographic work was carried on with the 6-inch DALLMEYER, strapped to the CLARK equatorial which was used as a setting and guiding telescope. A set of observations at a given zenith distance consisted always of five separate exposures of 1^s, 2^s, 4^s, 8^s, and 16^s duration, respectively. The driving-clock was kept running continuously during the exposures of each set, and to keep the separate images from overlapping, the telescope was shifted through a known angle (see page 33) in declination. As in previous similar work, the exposures were made by hand, the observer removing the cap at his zero count of the chronometer, and replacing it at the count corresponding to the proper number of seconds. The exposures of each set were arranged along a straight (short) line, and the different sets in parallel lines made in the order of observation. The chronometer times of the beginning and end of each set are given in the tables which follow:

EXPOSURES ON SIRIUS FOR PHOTOGRAPHIC ABSORPTION OF OUR ATMOSPHERE.

Series.	Chronometer Time.	
	March 31.	April 1.
I.	13^{h} 33^{m} —35^{m}	13^{h} 39^{m} —41½^{m}
II.	15 23 —25	14 36 —38
III.	16 42 —46	14 51 —53
IV.	17 18 —20	16 54 —55½
V.	17 44 —46	17 23 —25
VI.	17 51 —53	17 40 —41½
VII.	--------------------	17 50 —51¼

Occultation of *Sirius* (by mountain) on March 31 ....17^{h} 53^{m} 15^{s}.0
Occultation of *Sirius* by (mountain) on April 1 ....17 52 57 .3

April 3, 1893.

Nine sets of exposures were made, but the plate was worthless.

Occultation of *Sirius* ....17^{h} 52^{m} 53^{s}.0

April 12, 1893.

Series.	Number of Plate.				
	1	2	3	4	5
I.	13^{h} 30^{m} —32^{m}	14^{h} 12^{m} —14^{m}	14^{h} 23^{m} —25^{m}	14^{h} 33^{m} —35^{m}	14^{h} 43^{m} —46^{m}
II.	15 15½—17½	15 25 —27	14 34 —36	15 39 —41	15 45 —47
III.	16 33 —35	15 59 —61	15 7 — 9	16 10 —12	16 18 —20
IV.	16 58 —60½	16 26 —28	16 0 — 2	16 37 —39	16 46 —48
V.	17 16½—19	16 53 —55	17 28 —30	17 10 —12	17 15 —17
VI.	17 29 —31	17 21 —23	--------------	17 31 —33	17 37 —39
VII.	17 39 —41½	17 41 —43	--------------	--------------	--------------
VIII.	17 47 —49	--------------	--------------	--------------	--------------

Three different double plate-holders were used in securing the thirty-two series of exposures. Each plate will give an independent set of measures for determining the amount of the absorption.

April 14, 1893.

Series.	Number of Plate.			
	1	2	3	4
I.	14^h 14^m —16^m	14^h 7^m —19^m	14^h 21^m —23^m	14^h 23½^m—25½^m
II.	15 26 —28	15 29½ —31½	15 33 —35	15 35 —37
III.	15 56 —58	15 58 —60	16 2 — 4	16 5 — 7
IV.	16 34 —36	16 36 —38	16 39 —41	16 41 —43
V.	16 57 —59	17 2 — 4	17 4½ — 6½	17 7 — 9
VI.	17 22 —24	17 24½ —26½	17 28 —30	17 31 —33
VII.	17 33½ —35½	17 36 —38	17 38 —40	17 40½ —42½
VIII.	17 45 —47	17 46½ —48½	17 48 —50	----------------
IX.	----------------	----------------	17 50 —52	----------------

Altogether there were more than four hundred separate exposures made on *Sirius.* About nine-tenths of this number of images are available for the investigation of the atmospheric absorption at Mina Bronces.

The images for low altitudes are very satisfactory and much better than any heretofore obtained by me.

A brief description of some of the principal stellar photographs made at Mina Bronces, and which are now at the Lick Observatory, follows:

March 30, 1893.

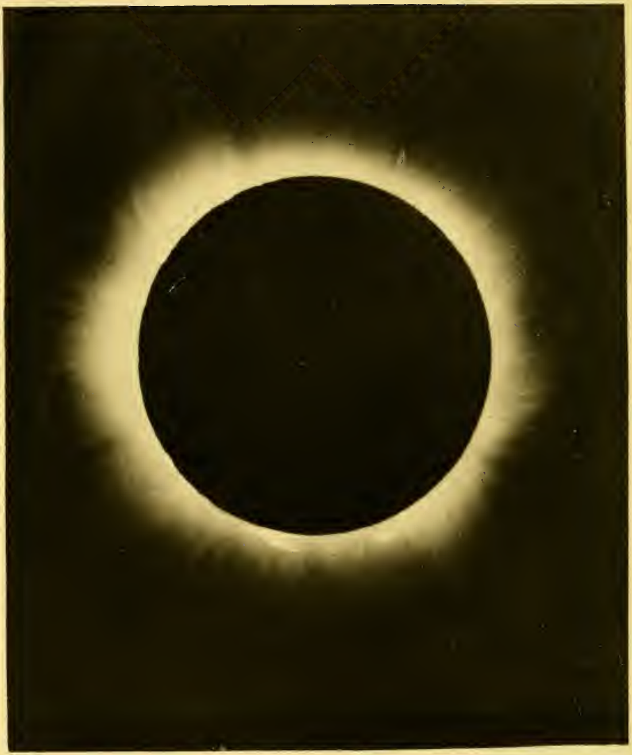
8x10 plate..............Interrupted trails of Southern Cross, 15^h 2^m to 15^h 25^m

April 1, 1893.

5x7 plate....From some experimental photographs of α *Centauri,* it was found that both components of this double star were well separated on the 5x7 plate placed in the focus of the equatorial (Clark lens).

A letter received a few days previously from an Eastern astronomer, asking for some micrometric measures of this star, led me to try the photographic plate, as no micrometer was available.

The clock was stopped after each instantaneous (very short) exposure, and after an interval of a few seconds another exposure was made—when the clock was up to the required speed. The position-angle can be determined from the direction of the line joining the successive images. The scale for distance was fixed by an exposure of 10^s on a group of three widely separated stars (β, γ, and ε *Canis Minoris*), in hour-angle 2^h 42^m at 14^h 42^m chronometer time. $\delta = + 9°$.



CORONA 16 APRIL 1893

April 3, 1893.

8x10 plate	Region of *Nebecula Major.* Exposure, 5^m
8x10 plate	Region of Southern Cross, $14^h\ 0^m$ to $14^h\ 5^m$
8x10 plate	Region of η *Argus*
5x7 plate	Instantaneous (very short) exposure on α *Centauri*, similar to those of April 1; same group of scale stars on plate, $14^h\ 42^m$

April 5, 1893.

8x10 plate	Mean $\delta - 46°$. Exposure, 5^m
8x10 plate	Mean $\delta - 52°$. Exposure, 5^m
8x10 plate	Mean $\delta - 58\frac{3}{4}°$. η *Argus* region. Exposure, 45^m

April 6, 1893.

8x10 plate	Region of South Pole (trails), $14^h\ 46^m$ to $15^h\ 1^m$
8x10 plate	Region of *Canopus*, $15^h\ 7^m$ to $15^h\ 17^m$
8x10 plate	Region of *Nebecula Major.* Exposure, 90^m

April 8, 1893.

8x10 plate	Region of α *Eridani*, $13^h\ 2^m$ to $13^h\ 12^m$
8x10 plate	Region of *Nebecula Major*, $13^h\ 18^m$ to $16^h\ 18^m$
8x10 plate	Nebulous region of Milky Way. Moonrise at close.

April 9, 1893.

8x10 plate	Exposed, $16^h\ 22^m$ to $16^h\ 32^m$
8x10 plate	Region of *Nebecula Major*, $13^h\ 7^m$ to $16^h\ 7^m$

April 12, 1893.

8x10 plate	Exposed, $14^h\ 52^m$ to $14^h\ 57^m$. $\tau = 9^h$. $\delta = 74°\ 9'$
8x10 plate	Region of *Canopus*, $15^h\ 6^m$ to $15^h\ 20^m$

All of the 8x10 plates were exposed in the DALLMEYER telescope.

(*D*) Of the terrestrial photographs made at Mina Bronces, little need be said here. The earlier ones were taken more particularly for experimentally testing the action of the developer.

Copies of some of these photographs have served as illustrations for preliminary papers published elsewhere. Plates III, IV, and V are *cross-cut* reproductions.

All the glass negatives of terrestrial views are 5x7 in size. The films are 4x5.

THE PHOTOGRAPHIC ECLIPSE PRINTS.

Plate I. (Silver Print.)

To obtain Fig. I, Plate I, a contact positive on glass was first made from an original DALLMEYER negative exposed 2^s. From this positive was obtained the contact negative on glass with which Fig. I was made.

On the original negative the faint outer coronal extension can be traced quite as far as the image of the planet *Venus*, which is shown as a white dot near the right-hand border and below the center of Fig. I (Plate I).

Some of the photographs have been printed much heavier than others, so that the outlines will vary somewhat in the different copies.

If the print is held in a slanting direction the extension can be traced nearly to the limits of the bounding rectangle.

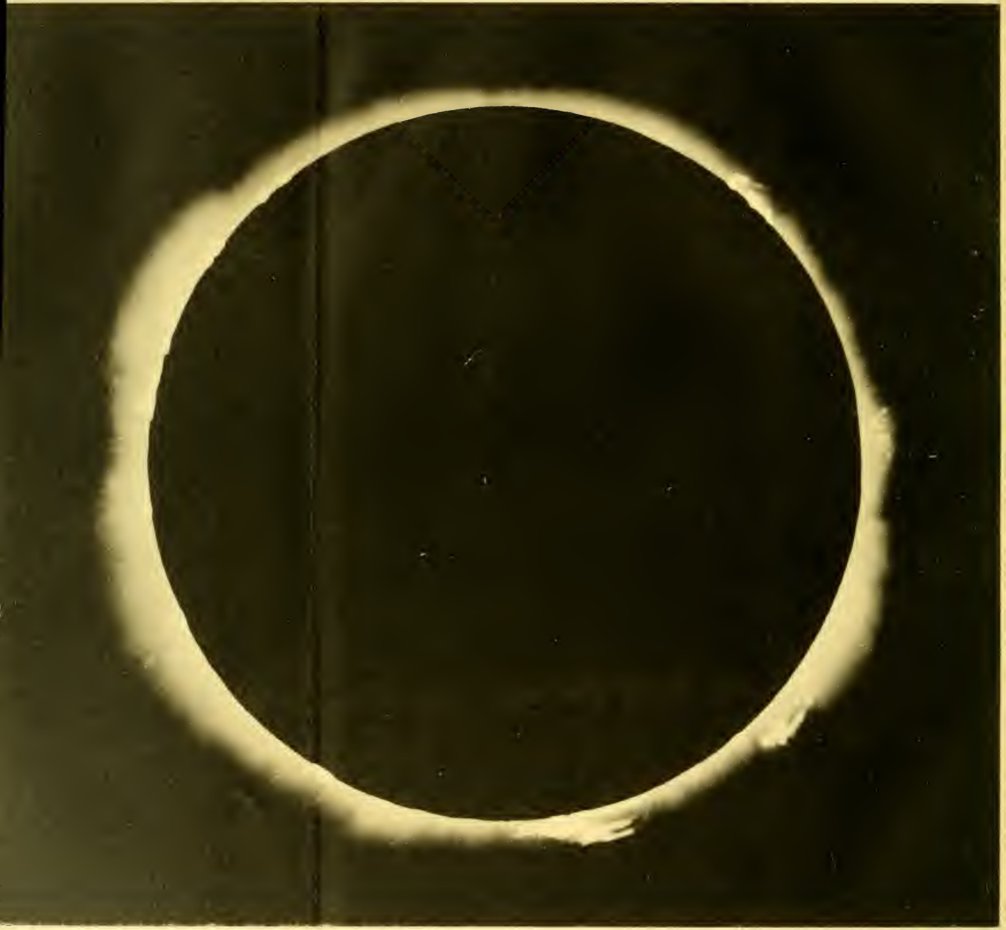
In the lower *right*-hand quadrant the tail of the comet will likewise be found to extend nearly to the lower line-limit of the photograph.

Prints II and III of the same plate are made from *positive* contact copies of portions of the original 18x22 negatives. As each additional reversal causes a loss of the finer details, it was deemed best to make *negative* prints for the remaining illustrations of this plate. Fig. II represents the inner coronal features between the position-angles 160° and 220°, showing the two great protuberances. Fig. III illustrates the appearance of the coronal arches between the position-angles 10° and 65°. Both photographs show the most detail on the less heavily printed plates.

Fig. IV is printed from a contact positive copy on glass of one of the DALLMEYER negatives. The head of the comet will be recognized in the lower *left*-hand quadrant. Fig. V is printed from one of Mr. COLTON's lantern-slide reductions of the 18x22 inch negatives. In I, IV, and V the sun's north pole is at the top in each case; but in IV and V the east point is toward the *left*. The prints II and III are also reversed. As all the 1,200 copies of the frontispiece were printed from the same glass photographs, the later copies show the deterioration of the film.

Plate VI.

This is a direct photo-copy of a reduced glass positive made by Mr. COLTON from No. 2 of the 18x22 inch plates. While this reduced copy on glass contains a very large amount of detail of the original negative, nearly all of the finer markings are lost in the illustration here given, which represents the best results so far obtainable with printer's ink. It seems that only



positives on glass can do justice to good negatives, and only such glass copies should be studied in special investigations.

Plate VII.

This illustration originally appeared in the October, 1893, number of *Astronomy and Astro-Physics.* It represents the full size of the moon's image on the 18 x 22 inch negatives, but is very far from doing justice to the original, as all the finer coronal detail is wanting.

A large number of reduced copies of the corona on glass, made by Mr. COLTON from the original negatives, have been widely distributed to the principal observatories and scientific institutions of the world. For special investigations of the inner corona, full-size copies on glass should be used.

PHOTOMETRIC MEASURES.

Two of the plates subsequently exposed in the CLARK equatorial had been standardized (by Professor LEUSCHNER) after the plan which Professor HOLDEN followed for the two eclipses of 1889, and at his request Mr. PERRINE of the Lick Observatory made careful photometric observations and measures of these two negatives. Mr. PERRINE's results are exhibited in Plate VIII, and his report follows here:

REPORT OF MR. PERRINE.

I have compared the relative actinic intensities of different parts of the corona of April 16, 1893, with standard squares impressed upon the negatives, in a manner similar to that of the eclipse of January 1, 1889, which is described in the Lick Observatory report of that eclipse, beginning on page 62. The squares were exposed by Mr. LEUSCHNER on January 8, 1893. I submit herewith the resulting diagrams.

Some experimenting was indulged in to determine the best means of illuminating the negative for the comparison. The method finally adopted was to support the negative in a frame in a vertical position near a west window, and a very finely ground glass was placed about an inch behind the negative to diffuse the light. This was found very satisfactory. Circular, isolated areas of the corona and squares, about one fortieth inch in diameter, were compared. Comparisons were made for each square at every 5° of position-angle around the entire corona, and the resulting distances from the moon's center, in minutes of arc, were tabulated. After the comparisons had been made and tabulated for each of the seven squares on each of the two negatives—over one thousand comparisons in all—the distances and position-angles were plotted to a scale three times that of the original negative and the curves drawn.

The times of exposures of the standard squares are 1^s, 2^s, 4^s, 8^s, 16^s, 32^s, 64^s; therefore, the curves correspond to the squares in the above order, beginning with the outermost, which is the 1^s curve. The outer portions of the corona are fainter than the 1^s square, and therefore are not represented.

The two standardized negatives used in the above comparison were made with the CLARK lens and designated as first series 4^s, from which Fig. 1 is deduced; and first series 2^s, from which Fig. 2 is the deduction.

C. D. PERRINE.

Lick Observatory, May 12, 1894.

OBSERVATIONS AND MEASURES OF THE SUN'S SURROUNDINGS, RESULTING FROM AN EXAMINATION OF THE ECLIPSE NEGATIVES.

Of the fifty-two negatives secured at the Lick Observatory station, only those taken with the 40-foot, the CLARK, and the DALLMEYER telescopes have been specially examined. The first mentioned contain detail near the sun, which could never be recognized in the smaller scale photographs, while the outer corona is best shown on the DALLMEYER plates.

Some of the longer exposures with the CLARK telescope would probably have shown certain features at several solar diameters from the sun more satisfactorily, owing to the larger scale, but, as already stated, the edge of the field of view cut off the more distant parts of the corona.

The comet first found on the Lick Observatory plates is, for example, fairly conspicuous on some of the CLARK negatives, as are also the general features of the inner corona. On the plates taken with the two landscape cameras, the scale is so small that no advantages over the larger negatives are apparent, so far as the corona is concerned. The large angular diameter

Fig. 1

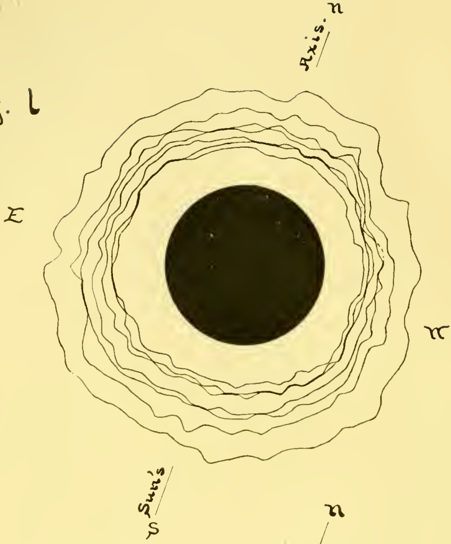
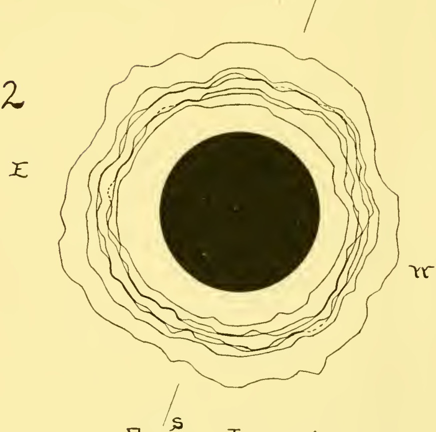


Fig. 2



Diagrams of the Actinic Intensity of the Corona of April 16, 1893; deduced from negatives by J. M. Schaeberle.

[Plate VIII.]

of the field of view made it possible to show the marked variation in the sky illumination at different altitudes, the outlines of Cerro Cobre Mountain, the planets *Venus* and *Jupiter*—all interesting features of the eclipse pictures taken with the small cameras.

For convenience in referring to certain objects, the more conspicuous parts of the inner corona have been represented in a skeleton diagram made with the aid of the eight 18 x 22 negatives.

The negatives were singly and successively placed in a horizontal position on a heavy and still larger piece of plate glass, to avoid the danger of fracturing the negatives as the observer was tracing, in ink, the coronal lines on another piece of glass placed upon the negative. An ordinary mirror, inclined at the proper angle, reflected the light from a window by day and from a lamp by night, up through the negative, making it convenient to obtain a fairly accurate ink tracing on the glass.

On the back (glass) side of each negative, the markings it was desired to copy were first traced. This was found to be necessary, as the fainter lines of the negatives would not show well when compared with the definite lines of the diagram on the glass, through which the observations were now made.

The positions of the different coronal lines in ink on each plate could thus be readily recognized, even after many heavier lines had already been drawn on the superposed tracing.

To obtain the exact position of the sun's center for each plate, the main features—moon's outline, prominences, arches, conspicuous streamers, etc.—were first traced upon the superposed glass plate. A circle was then drawn tangent internally to the moon's outline at the point of second contact, the radius of the circle being equal to the computed radius of the sun's focal image.

The first exposure, it will be remembered, was made immediately after the second contact.

Plate No. 2 was then oriented wholly by means of the protuberances, arches, and conspicuous inner coronal markings; similarly for Plates No. 3 and No. 4. The stream lines of the longer exposures were continued from those of the shorter-timed negatives, so that while the detail of the inner corona, including the prominences, was all burnt out in plates 5, 6, and

7, not the slightest doubt as to the orientation of these plates existed, as each conspicuous line on the back of any given negative was of necessity bound to coincide with, or form the continuation of, a corresponding line of the previous tracing on the glass. Plate No. 8 was only used to insert the lower portions of the conspicuous prominences near the south pole, and to check the position of the line of the moon's motion.

This accounts for the fact that in the diagram the prominences in the third quadrant are shown quite close to the sun's limb, while the streamers—inserted from the plates on which the moon's image cuts off the corona—begin at a greater distance from the sun. On Plate No. 8 the arc of the sun's image from 210° to 280° is impressed upon the negative, and although the exposure was made as short as possible, the solarization of the plate in this position-angle was so great that a reversal of the image resulted.

As the plates 7, 6, and 5 had comparatively long exposures, the detail close to the moon's disk is lost in the general overexposure of the inner corona; any low-lying protuberance between 210° and 270° position-angle would therefore not be shown on these plates, for during the short exposures they were covered by the moon's disk. As there are no indentations in the moon's outline along this arc, probably no conspicuous protuberances were visible in that position, which remark applies also to the two polar regions of the sun. Only by having at least two additional stations—one near the northern, the other near the southern limit of the moon's shadow-path—could these lower polar regions have been photographed, as would be the case for any total eclipse of several minutes' duration.

Those eclipse observers stationed farther north (or south) should have more north (or south) polar prominences on their plates than were visible on the central line.

Reference numbers (and letters) have been assigned to the more conspicuous masses exterior to the sun. For convenience and brevity the distance of a point from the sun's invisible limb will be called h; the position-angle, measured from the north *celestial* pole around to the east through 360°, will be called p, and the inclination of a stream line to a normal, through its base at the sun's disk, will be called $+i$ or $-i$, according as the more elevated portion of the stream is in greater or less position-angle than the base of the stream.

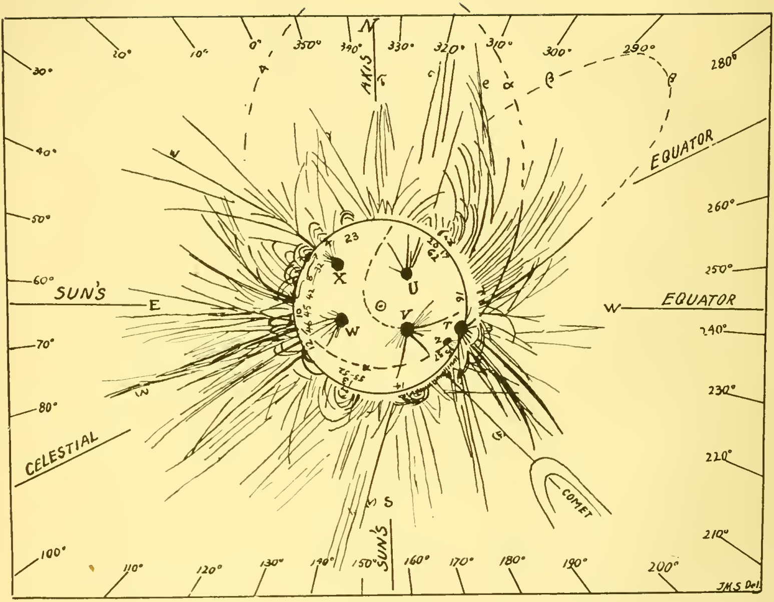


Plate IX. Skeleton Diagram of Corona.

DESCRIPTION OF PROMINENCES VISIBLE ON THE 18x22 INCH PLATES.

On Plate No. 1 practically the whole arc of the moon's outline from p = 7° to p = 82° is bordered by a succession of prominences of varying height, (the instant of exposure being only about one second after the beginning of totality). To avoid confusion, however, the more elevated regions showing as separate masses on the other plates will be given separate numbers. All stream lines mentioned form portions of elliptical arcs with major axes normal to the sun's surface, so far as the observer can judge from the short arcs visible.

No. 1. $p = 4°$. $h = 0'.8$. Top just visible at moon's limb.

No. 2. $p = 7°$. $h = 0'.8$. Top just visible at moon's limb.

No. 3. $p = 9°$. $h = 0'.8$. From the top of this prominence two slender arches span the interval to No. 4.

No. 4. $p = 11°$. $h = 1'.0$. A prominence in the form of a very eccentric arch. From its top a flat arch spans the space to No. 5, which it joins near the top, leaving an opening above the intermediate lower stream-like protuberances which form the continuous border joining No. 4 and No. 5. A number of large coronal arches end at or near this protuberance.

No. 5. $p = 17°$. $h = 1'.0$. This mass is produced by a number of dense streams which cross each other, the inclinations being in opposite directions.

No. 6. $p = 18°$ to $p = 27°$. $h = 0'.5$ to $h = 0'.2$. A series of low-lying arches, forming a nearly level surface, whose altitude continually diminishes until the base of No. 7, almost at the sun's limb, is reached. From this whole surface a large number of high coronal arches radiate on both sides of the normal.

No. 7. $p = 30°$. $h = 1'.0$. This prominence is simply a mass of interlacing streams rising to a greater height than the average, and forming one extremity of the mass described in No. 8.

No. 8. The whole area included between a line drawn tangent to the sun's limb in $p = 43°$ and the sun, from $p = 30°$ to $p = 58°$, is one mass of protuberances. From this nearly plane surface numberless coronal arches have their origin, the apparent eccentricity varying from a right line projection to a nearly circular one. A close inspection at once reveals the unmistakable fact that this whole mass is made up of interlacing arches, most of them being quite flat. On each side of the point of tangency (p = 43°) the arches gradually grow higher with increasing distance, reaching their maximum heights, h = 1′.0 and h = 1′.2 in p = 30° and p = 58°, respectively, near which points the less dense spaces between the intersecting arches make it possible to follow the individual streams throughout their visible length. In p = 47° the upper part of a very dense arch projects 0′.3 above the general level; at this same point ends a low, flat arch, which starts from this surface in p = 55°, and rises above it. One of the conspicuous coronal arches starts from this same projection. From the very extremity of this mass in p = 58°, a knotted and partly discontinuous arch reaches an altitude h = 1′.3, where it vanishes in p = 53°.

No. 9. From p = 59° to p = 69° there is a level stretch of protuberances having a mean altitude h = 0′.7. From five slight projections in this surface as many different coronal arches spring.

No. 10. An arch begins in p = 69° as a dense narrow band, which gradually widens, as the altitude increases, to h = 1′.0; it returns in p = 77°, where its width is greatest. From near this extremity two other arches begin, but disappear a short distance beyond their maximum elevation, which is h = 1′.0. Almost a miniature of No. 15.

No. 11. From p = 77° to p = 83° the moon's limb is very serrated, owing to the fact that only the more elevated portions of the nearly level surface project beyond the limb, causing the indentations (seven in number).

No. 12. Two small intersecting arches p = 93°, h = 1′.0 and h = 1′.1. The former ending at the moon's limb in p = 87°, and the latter disappearing at its maximum altitude in p = 96°.

No. 13. p = 125° to p = 130°. h = 1′.5. The knotted appearance of this mass, the top of which projects but very little beyond the moon's limb, plainly shows that several different streams united to make this prominence, which was very bright, as shown both by the blackness of the film and the decided indentation in the moon's limb.

No. 14. p = 165° to p = 201°. From this long arc of numberless arches rises one of the two prominences which form such conspicuous features of this eclipse.

On Plate No. 8 the low-lying protuberance matter, which, on all the other eclipse photographs I have seen, appears as a continuous mass, is here shown to be composed wholly of streams of ejected matter. While the confusion due to the many perspective overlappings is very great, no less than forty different streams can be counted within the above limits.

The first portion of this greatly disturbed region which is shown on the plate begins in p = 166° at the moon's outline (which at this point is 1′.0 above the sun's limb), and rises in the form of two much-knotted arches to heights of 3′.2 and 2′.4, respectively. Near but just a little beyond their highest points each arch changes abruptly into a very fine stream (forming a continuation of the original knotted arches); both end in the general less elevated mass of streams, one in p = 181° and the other in p = 180°, respectively. These two main arches are crossed and re-crossed by numerous other arches. From p = 162° to p = 166° are what at first glance seem to be two nearly horizontal streams at h = 2′.0 and h = 1′.8. The knotted appearance and the zigzag form of the markings indicate that these two streams are really portions of several other streams which reinforce each other where they overlap in projection.

From p = 169° to p = 192° the average height of the general mass of streams declines from h = 1′.8 to h = 1′.0. In p = 193° a sharp rise begins, so that in p = 197°, h = 1′.5, which appears as an isolated protuberance on the other plates, owing to the moon's motion. From this latter point the fall is sudden to the sun's limb in p = 201°. This whole end of the prominence has the appearance of being a disconnected portion of No. 15.

Inclosed by the two main arches first described is a third nearly parallel and very similar arch, which rises from the general mass in p = 169°, reaches the height h = 1′.8, and returns to the main mass in about p = 180°. Between this arch and the main arches are two other parallel streams, which disappear, however, before completing the first half of the arch. The peculiarity of nearly all the streams composing the nearly horizontal mass is that only the first half of each arch is complete, and that with the exception of the two extremities all the arches have the same height. Here, as in several cases already cited, the maximum activity is confined more to the borders of a large disturbance.

No. 15. This is the second group of the two conspicuous prominences. The main features are two nearly parallel, incomplete arches, which leave the moon's outline in p = 215°, rise to heights of h = 3′.8 and h = 3′.0, then near their maximum height come to a rather abrupt termination in p = 202°, at which point a slender stream starts from the moon's outline and just reaches the lower edge of the inner arch. The main arches are knotted, and, as in other similar cases, these knots are shown to occur at those points where other streams appear to cross. A closer inspection will reveal the fact that each of the main arches is really composed of two slender, nearly parallel streams seemingly bound together by the knot-like condensations. Near its highest point a portion of the upper stream bends towards the sun with a less radius of curvature than other portions of the same arch, as though some resistance to motion had been experienced. This portion of the stream is also somewhat denser than the average.

No. 16. p = 250°. h = 3′.0. A rather interesting, tree-like structure formed by the overlapping of a number of discontinuous streams inclined about 30° to the *normal*. From the top of the most conspicuous one, a coronal arch which forms the continuation of the prominence rises to h = 3′.4, returns and cuts the moon's outline in p = 244°, the distance between the limbs of the sun and moon images at this point being 2′.1.

No. 17. A pyramidal prominence rises almost from the sun's outline in p = 284° and runs to a point at h = 1′.0. Inclined to the normal about + 30°.

No. 18. Similar to No. 17, near which it begins in p = 286°, rises in the form of an incomplete or discontinuous arch to h = 1′.6, where it ends on the lump-like mass No. 19.

No. 19. p = 289° to p = 291°.5. A detached protuberance having the same general inclination as the upper portion of No. 18, with which, however, it does not seem to form a part. The altitudes of the upper and lower bounding lines are, respectively, h = 1′.8 and h = 0′.8. Passing through the upper portion of this detached mass is a portion of another arch. There are detached portions of three other arches beneath No. 19.

No. 20. A columnar structure, which rises to a height of h = 2′.2 in p = 294°. At the moon's limb it is inclined about + 10°, but near the upper extremity a seeming reversal of the inclination takes place. A close inspection reveals the fact that a number of different streams go to make up this column, causing the observed reversal of curvature for the whole mass, which has a breadth of about 0′.5.

From the very top of this protuberance a fine knotted stream rises and runs toward the equator inclined 60° to the normal, and disappears in $p = 289°$ at $h = 2'.8$. A faint arch, starting near the base of No. 20, also joins the knotted stream along a tangent.

No. 21. $p = 300°$ to $p = 302°$. $h = 0'.8$. Several portions of arches just visible above the moon's limb. The first in $p = 300°$ to $p = 301°$ is faint; the second is very dense, but shows plainly as a loop; the third shows only as a black patch on the moon's edge. The whole system indents the moon's outline very markedly.

No. 22. A very slender, discontinuous portion of a stream in $p = 359°$; $h = 1'.0$; inclined $+ 30°$ to normal; length of arc, about 0′.2.

The numbering in the preceding list of *prominences* proper refers, as a rule, to the aggregations of streams, and not to the individual members of a group; only where a single isolated stream is found, has a separate number been given. Counting all the individual streams of prominence matter visible on these plates, the number runs considerably above one hundred.

All the evidence given by the prominences therefore leads to the conclusion that this matter is in rapid motion, and that instead of rising from the sun's surface in irregular masses, the structure is just as definite as is found to be the case in the coronal streamers. In other words, every prominence and protuberance visible during this eclipse was made up of individual streams of matter apparently moving in elliptical orbits, with the sun in one of the foci. The almost certain conclusion seems to be that all prominences are of the same general structure, and that the chief cause why this structure has not been more generally recognized is due to the want of sufficient scale and definition, as shown by a comparison of the results obtained on April 16, 1893, of the eclipsed sun photographed at Mina Bronces, and the published spectroscopic results of the uneclipsed sun observed at other places on the same day by Professors HALE and FENYE.

THE CORONA PROPER.

Under this title, all the remaining matter visible in the sun's immediate neighborhood, not included under the heading of prominences, will be considered.

The coronal structure of this eclipse is apparently governed throughout by a single, simple law, viz.: *The matter is arranged along portions of elliptical streams, one focus of the ellipse being at the sun's center.*

Practically, only two principal forms are recognized on the plates, one being that visible portion of the stream which returns to the sun, forming a portion of an arch or the complete arch, while in the other form less than one half the stream is visible; that is, the matter becomes invisible, photographically, before reaching its greatest distance from the sun. The first named form will be called a coronal arch; the second form will be called a streamer; the real distinction between the two being chiefly one of extent, the streamer reaching farther from the sun.

THE CORONAL ARCHES.

On the 18 x 22 inch plates the moon's outline is bordered by a fringe of arches which vary in height from $h < 1'$ to $h > 10'$. They are most numerous in the equatorial regions, but are found in nearly all position-angles. As in the case of the protuberances, only the more conspicuous *coronal* arches will be given numbers, and to avoid confusion the numbering will be made continuous with the protuberances. In describing the form, the position of the arch with reference to an underlying or neighboring protuberance will be given, or if it is isolated the position-angle will be recorded. In addition to the altitude (h) of the highest portion of the coronal arch, the distance (breadth) $\pm \triangle p$ between the two legs of the arch, measured in degrees, will also be inserted. $\triangle p$ is always measured from the leg which is most dense and best defined, presumably the ascending end of the arch; when $\triangle p$ is +, the second leg has a greater position-angle than the one taken as the origin; if $\triangle p$ is —, just the reverse is the case.

In cases where the moon cuts off the bases, or where the density is so great that the lower portions cannot be traced with certainty, the distance $\triangle p$ has been taken equal to the arc of the sun's limb included between two lines drawn tangent to the lowest visible portions of the arch. The values of $\triangle p$ will therefore only be approximately correct.

Nos. 23–25. $p = 2°$. Just above Prot. No. 1. Three arches certain, others indefinite. They rise to $h = 2'.9$, $h^{i} = 1'.8$, $h^{ii} = 1'.4$, $\triangle p = 12°$, $\triangle p^{i} = +6°$, $\triangle p^{ii} = ?$

Nos. 26–31. A series of at least four overhanging arches start up from near the middle of the protruding area No. 6 in $p = 24°$, $h = 4'.5$, $h^{i} = 4'.0$, $h^{ii} = 2'.9$, $h^{iii} = 2'.1$, $h^{iv} = 2'.1$. They seem to have a common origin, and also to end in nearly the same position-angle, spanning an arc $\triangle p = -12°$. The appearance is much the same as water spouting from a fountain inclined several degrees to the normal. (See Plate I, lower portion of Fig. III.)

Nos. 32–42. This is the much-disturbed locality of numerous arches overlying the region of protuberances from No. 7 to No. 9. The confusion from the numerous interlacings is so great that only the more conspicuous ones can be traced throughout the whole arch. The average altitude is $h = 4'.0$, and the average span is $\triangle p = \pm 17°$. Over Prot. No. 8, and also in $p = 47°$, are several higher arches, which rise to $h = 5'$ and more. In about $p = 47°$ a number of very dense, short, vertical streams are seen to curve sharply back towards the sun on both sides of the normal at $h = 2'.5$, giving exactly the appearance so familiarly observed in ordinary water fountains. (For a photographic print of this region, see Plate I, Fig. III.)

No. 43. A delicate coronal stream which ascends from Prot. No. 9 in $p = 62°$, crosses the arches Nos. 22 and 23 at $h = 4'.2$, its maximum altitude; returning towards the sun its estimated span is $\triangle p = +15°$.

No. 44. Starting from the same point as No. 43 is a lower and very much heavier arch, having the constants $h = 2'.5$, $\triangle p = +20°$. Inclosed within this last-named arch is the beginning of another similar one, which, however, can only be traced to its point of intersection with No. 22 at about $h = 2'$. On this same protuberance (No. 9) in $p = 62°$ rests the leg of the most conspicuous of the coronal arches described under Nos. 32–42. The constants of this particular arch are $p = 46°$, $h = 3'.8$, $\triangle p = +16°$.

Nos. 45–46. Rising from Prot. No. 10 in $p = 70°$ are two similar high arches which lie on opposite sides of the normal. At first glance the one in less position-angle appears distorted, an effect caused by one of the more prominent inclined streamers seeming to form one of the legs, which thus appear to be parallel and inclined some $+ 15°$ to the normal, and apparently having the constants $h = 6'.0$, $\triangle p = + 4°$. Eliminating the effect of the inclined streamer by a closer inspection, the true leg of this arch is faintly shown in $p = 62°$; it joins the distorting streamer in $h = 4'.0$, where it is lost, only to reappear near the top of the arch. The true constants are found to be $p = 70°$, $h = 6'.0$, $\triangle p = - 8°$, the value of $\triangle p$ being negative, as the other leg of the arch is now the heavier. The constants of the companion arch are the same, except that $\triangle p = + 8°$.

No. 47. From the same point, in $p = 70°$, another arch begins, having the constants $h = 3'.8$, $\triangle p = + 14°$.

No. 48. Arch. $p = 78°$, $h = 3'.7$, $\triangle p = + 12°$.

No. 49. Conspicuous arch. $p = 88°$, $h = 2'.5$, $\triangle p = + 20°$.

No. 50. Same origin as No. 49. Quite dense. $h = 2'.0$, $\triangle p = + 10°$.

No. 51. Only the upper portion of the arch can be traced with certainty. There seem to be two concentric arches involved, as a striking feature of this structure is the arc of less density formed by the bounding arches. The center is in $p = 95°$; the altitudes are $h = 5'.4$, $h^{i} = 4'.5$; a rude approximation to the span is $\triangle p = 25°$.

Nos. 52–55. A most remarkable system of nearly concentric arches, which are quite symmetrically arranged with reference to Prot. No. 13. Only the values h and $\triangle p$ are given, as the axes of all these arches are nearly in $p = 127°$, it being understood that $\frac{1}{2} \triangle p$ is measured each way from each axis. $h = 12'.0$, $\triangle p = ?$ Only the highest, nearly horizontal portion of this arch can be traced with certainty through 10° or 15° of arc. $h^{i} = 8'.0$, $\triangle p^{i} = 35°$; $h^{ii} = 7'.0$, $\triangle p^{ii} = 30°$, composed of several nearly parallel streams; $h^{iii} = 5'.0$, $\triangle p^{iii} = 20°$, also made up of a number of close arches. At first glance the legs of the inner arch seem to suffer a reversal of inclination, giving the appearance as though the coronal matter was revolving in a nearly circular orbit about a point far above the sun's surface. This false curvature is caused by several much inclined osculating streamers, which here show quite plainly. To illustrate the deceiving part played by the streamers, two special cases will here be noticed. From the top of Prot. No. 13 a narrow white streak (white on the negatives) appears to issue, inclined about — 10° to a normal; it is blotted out by a portion of an arch at h = 3′.0. A similar white streak is in the + interior end of the arch, but lies on the opposite (+) side of a normal. Both of these white streaks are plainly shown to be simply the less dense portion (of the interior) bounded on each side by nearly parallel streamers, causing an increase in density, and a false continuation of the lower portions of the intersecting arches. (All the white streaks at other parts of the negatives are plainly shown to be due to contrasts caused by the presence of sharply bounded coronal matter, in the form of slightly separated parallel streams.)

Other arches in this same locality are too indefinite to admit of being traced with certainty. The two principal centers of disturbance seem to lie at about equal distances on each side of Prot. No. 13.

No. 56. Outer boundary of a faint arch; the leg in greater position-angle is at p = 152°, h = 4′.5, △ p = — 15°; probably belongs to the preceding group, but the other leg is lost in the heavier arches. There are indications of a number of arches between h = 4′ and h = 7′, directly over Prot. No. 14, recognized by the presence of great white arcs, caused either by greatly inclined streamers or arches of great span.

No. 57. The axis of an arch passes directly through the highest portion of the remarkable series of eruptions between Prot. No. 14 and No. 15. It is in p = 197°, h = 5′.5, △ p = 18°. A striking right-line vacancy (white line) starts from near the — leg of this arch; the streamers are inclined + 35° to the normal. Some of the arches described under No. 14 and No. 15 might well be classed under coronal arches.

Nos. 58–59. Two arches which probably have the same origin in p = 230° ± (the moon's limb is about 2′ from the sun's limb on the plates showing the arches, so that the origin cannot be well determined), h = 5′.0, h′ = 3′.5; the span for both arches is in the neighborhood of △ p = — 20°.

The highest portions of a large arch, which apparently starts near the sun's equator, is directly over this region. $h = 9'.0$, $\triangle p = 40° \pm$.

No. 60. Axis of arch in $p = 227°, h = 5'.0$; the span is uncertain, as only the higher portions can be seen; $\triangle$ p is probably between 15° and 20°.

No. 61. A coronal arch, already described in connection with Prot. No. 16.

No. 62. The remarkable series of nearly parallel streamers begin at the sun's equator with a considerable inclination to the normal, gradually become more curved in the higher regions, until the neighborhood of the group of Protuberances Nos. 17, 18, 19, and 20, where the streamers seem to take the form of arches, of which, however, only the — leg can be certainly recognized. From the sun's equator to this series of protuberances no less than twenty-five very distinct streamers can be counted at the moon's outline, and the ones in greater position-angle—say the last three—have their highest visible portions parallel to the sun's surface at $h = 6'$ (directly over Prot. No. 20) in $p = 294°$. As in the similar series of arches Nos. 52–55, the interior is crossed by a number of streaks and patches of less density. There is a suspicion of several low, flat arches in the neighborhood of $p = 300°$,but with no definite boundaries. The remaining 60° of the circumference are apparently quite free from arches, as well as protuberances.

THE CORONAL STREAMERS.

The photographs taken with the 40-foot telescope practically demonstrate that the corona is composed of streams of matter, and further, that these streams lie on the arcs of ellipses which have one of their foci at the sun's center.

For the convenience of description, as already stated, when the visible portion of a streamer can be traced beyond its seeming aphelion point, it is called an *arch;* when only one leg of the arch is visible, and this disappears before it reaches the apparent aphelion point, the visible portion is called a *streamer.* On Plate No. 1 the bases of streamers can be recognized in all position-angles. As it will be impracticable to enumerate them all, only the more conspicuous ones are here noticed. They will be designated by the letters of the Greek alphabet, α, β, γ, etc.

(α) A heavy streamer, remarkable for its great inclination to the normal. Producing the visible arc backwards, it cuts the sun's disk in $p = 228^\circ$; its inclination (i) to the normal at this point is $i = +56^\circ$. At an altitude $h = 17'$ (in $p = 281^\circ$) its inclination (i′) to the same normal through its base is $i' = 99^\circ$.

(β) A heavy streamer from the equatorial region, not far from α. It is the most conspicuous of the several adjacent and nearly parallel streamers. Producing β backwards, it cuts the sun's disk in $p = 242^\circ$; its inclination $i = +28^\circ$. At $h' = 27'$ (in $p = 267^\circ$), $i' = 47^\circ$.

(γ) The most isolated and conspicuous one of several parallel and nearly rectilinear streamers. It cuts the sun's disk in $p = 339^\circ$; the inclination to the normal is $i = +23^\circ, h < 30'$.

(δ) A stubby streamer, very heavy up to $h = 10'$; forms the nearly normal boundary separating coronal areas of unequal density. $p = 22^\circ$.

(ε) A narrow, nearly rectilinear streamer, having apparently no companions. Produced backward it cuts the sun's outline in $p = 16^\circ$; the inclination is $i = +19^\circ$, $h < 30'$.

(ς) A remarkably heavy portion of a much curved streamer, which suddenly disappears at $h = 8'$. It begins in $p = 60^\circ$, inclined $i = -18^\circ$ to the normal. At $h = 8'$ (in $p = 47^\circ$) the inclination to the same normal is $i' = -75^\circ$. (Portion of an arch.)

(η) The most prominent of several nearly parallel streamers. Starts near base of ς in $p = 61^\circ$; the other constants are $i = -2^\circ$, at $h = 22'$ (in $p = 48^\circ$) $i' = -30^\circ$.

(θ) A nearly radial and rectilinear streamer in $p = 66^\circ$, $h > 30'$.

($\varkappa$) This sharply defined boundary is really made up of a number of different streamers, having slightly different inclinations, but which are tangent to each other at various distances from the sun. The combined effect of all is to give the boundary the appearance of a single streamer which suffers one or more reversals of curvature in its nearly normal path away from the sun. It begins in about $p = 79^\circ$, where the numerous shorter streams at the sun's outline have a general inclination of about $+10^\circ$. At $h = 10'$ (in $p = 80^\circ$) the inclination to the normal through the base is apparently $+12^\circ$. At $h = 20'$ the boundary is along a normal in $p = 83^\circ$; here there is an apparent reversal of curvature from + to —, plainly shown to be due to streamers coming from a greater position-angle, which are less conspicuous at lower altitudes, owing to the general lack of coronal matter in the rift which these streamers cross. At h = 25′ (in p = 82°) these last-mentioned streamers are parallel to the normal through the base in p = 78°, and from here on they gradually cease to form part of the boundary, curving more and more in a minus direction. At h = 30′ the more powerful, nearly radial, streamers seen within the general area bounded by this series of osculating lines break through the last-mentioned streamers, and from thereon make the remainder of the now normal boundary of this seemingly remarkable coronal feature.

(λ), (μ) The whole arc of this part of the sun's outline from ϰ to μ is covered with well-defined streamers, having a decided + inclination of about 10°. Within this area the three most prominent ones are ϰ, λ, and μ, which rise to h > 30′. λ and μ begin in p = 87° and 95°, respectively.

(ν) The heaviest of a band of nearly parallel and rectilinear streamers, covering about 25° of the sun's arc, rising to h > 30′. ν is inclined — 23° to the normal through its base in p = 164°.

(ξ) This streamer is remarkable chiefly for two reasons. In every other case of conspicuous streamers there were always at least several nearly parallel neighboring companions, but with ξ this is not the case. It stands wholly alone, and is rendered conspicuous, as it crosses other streamers in its nearly rectilinear and radial path to the most remarkable and only abnormal object on the plates, the object which I have since proved to be (and what was at once suspected to be) a *comet.*

The streamer ξ starts from the sun's surface in p = 198°, and is inclined + 2° to the normal; it can be traced to a distance h > 30′ — within the main body of the comet.

(π) The heaviest of a number of much inclined and conspicuous streamers issuing between p = 230° and p = 250° of the sun's outline. It leaves the sun's disk in about p = 231°, and its inclination is i = — 32°. At h = 20′ the approximate inclination is i′ = — 40°, but on account of the numerous crossing of streamers from greater position-angles the individual directions cannot be ascertained with certainty. At about p = 210° the bunching up from intersections is so great that from h = 10′ to

$h = 15'$ an apparent increase of density in the corona takes place.

(ρ) This is not a single streamer, but a boundary made up of a large number of nearly osculating streams from different parts of the sun's surface, intersecting each other at very small angles. The nearly continuous boundary thus formed has its origin in about 270°. At this point numerous arches roughly parallel to the great streamer (α) have their origin, and form the lower boundary—or, rather, boundaries—of the great wing of matter which at its most remote part is directly over the sun's north pole, and at a distance of several solar diameters from the sun. At $h = 25'$ (in $p = 307°$) the direction of curvature changes on account of the greater density of some more nearly radial streamers, which come from points on the sun's outline in greater position-angles; the general inclination to the normal at this point, although small, is, however, still $+$.

The other boundary (σ) of this same wing is caused by streamers which are almost exactly radial, and which occupy the whole area of the wing beyond $h = 30'$.

The lower interior portion of this wing is shown to be crossed and re-crossed by very much inclined streamers, the curvatures, so far as shown, corresponding to elliptical arcs, with normal major axes.

(σ) The nearly radial streamer forming one of the other boundaries to the great wing mentioned above; it is in $p = 320°$, $h > 30'$.

(τ) Also a radial boundary of the great wing $p = 335° \pm$, $h > 30'$.

There are a number of bands which at first glance appear to be much less dense than the surrounding coronal matter. In every case, however, these bands are shown to be caused by nearly parallel streamers, which bound the band on each side. One of the most conspicuous markings of this character starts at the sun's outline, just under the end of the great Prot. No. 15, in $p = 205°$, having an inclination $i = -45°$. The width of this band is about $0'.5$; the two straight parallel bounding streamers can be readily distinguished. This particular band is faintly shown in the silver print Plate I, Fig. II (just clearing the lower end of the upper prominence), and appears on all the shorter-timed negatives taken with the 40-foot telescope.

The skeleton diagram given in Plate IX can be advantageously studied in connection with the foregoing descriptions of prominences, coronal arches, and streamers, bearing in mind, however, that only the most conspicuous features shown on the 18x22 inch plates are there approximately represented.

THE OUTER CORONA.

With the exception of the more distant parts of the streamers mentioned under the preceding headings, all the forms thus far described belong properly to what has been called the *inner* corona, although there is no truly characteristic difference between the inner and outer coronal forms. The streamers, as they become fainter and more diffused, lose their sharp boundaries, and the wing-like appendages are formed wherever the streamers are most numerous in projection, which will evidently be where sets of streamers coming from different parts of the sun's surface cross each other; one of the outer boundaries in such cases conforming to the general direction of one set of streamers; the other boundary will be parallel in a general way to the other intersecting set of streamers. These boundaries, of course, tend to converge to a point, and the diverging areas beyond are with increasing distances rendered too faint to be visible. This structural form of the wings is very plainly shown on the 18x22 inch plates, and no doubt exists as to the method by which the wings are produced.

The DALLMEYER negatives are best adapted for showing the general form and greatest visible extent of the outer corona. The position-angles and extent of the main wings with reference to the sun's surface depend very largely upon the amount of light secured by the plate, viz., upon the ratio of aperture to focal length, and upon the duration of the exposure. The data given here are obtained from a plate exposed 2^s in the DALLMEYER telescope with the aperture cut down to three inches, the diaphragm being placed between the lenses.

Wing.	Position-Angle.	Greatest Distance from Sun's Surface.	Remarks.
1	20°—95°	>150′	The east equatorial extension of the corona.
2	110	> 90	
3	145	> 90	
4	170	> 90	
5	190—285	>200	The west equatorial extension.
6	325	>100	
7	350	> 75	

Several minor wings formed by nearly radial streamers entering the "gaps" between the wings are not included in the above list.

The preceding data relating to the more important coronal features are tabulated below; all the position-angles are now referred to that point where the sun's axis produced cuts the sun's limb, in projection. As heretofore, the angles increase towards the east.

Number.	Angular Distance from Sun's North Pole.	Altitude above Sun's Limb.	Inclination to a Normal at Sun's Limb.	Span of Arch.	Notes.
Protuberances.					
1	30°	0′.8			
2	33	0 .8			
3	35	0 .8	----------	--------	Two slender coronal arches also rise from top.
4	37	1 .0	----------	--------	Connected at base with No. 5. } Numerous coronal arches.
5	42	1 .0	----------	--------	Connected at base with No. 4.
6	44—53	0.5—0.2	----------	--------	A long series of low-lying arches.
7	56	1 .0	----------	--------	Part of No. 8.
8	56—84	10—1.2	----------	--------	A region of numberless protuberances and coronal arches.
9	85—95	0 .7	----------	--------	A region of arches, both protuberant and coronal.
10	95—103	1 .0	----------	--------	A miniature of No. 15.
11	103—109	0 .2	----------	--------	Serrations in moon's limb.
12	119—122	1.0—1.1	----------	--------	See "Remarks."
13	151—156	1 .5			
14	191—227	3 .2—	----------	--------	Great prominences. (See "Remarks.")
15	241—	3 .8—	----------	--------	Great prominences. (See "Remarks.")
16	276°	3 .0	----------	--------	Tree-like protuberance.
17	310	1 .0	+30°		

Number.	Angular Distance from Sun's North Pole.	Altitude above Sun's Limb.	Inclination to a Normal at Sun's Limb.	Span of Arch.	Notes.
18	312	1.6			
19	315—317½	1.8	-----	-----	A detached protuberance.
20	320	2.2	+10°	-----	See "Remarks."
21	326—328	0.8	-----	-----	Portions of arches.
22	25	1.0	+30°	-----	Very small; discontinuous.
Coronal Arches.					
26–31	50	4.5—2.1	-----	12°	See "Remarks."
32–42	56—95	4.0	-----	17	See "Remarks."
43	62	4.2	-----	+15	
44	62	2.5	-----	+20	Incloses another arch.
45–46	96	6.0	-----	± 8	
47	96	3.8	-----	+14	
48	104	3.7	-----	+12	
49	114	2.5	-----	+20	Conspicuous.
50	114	2.0	-----	+10	Dense.
51	121	5.4—4.5	-----	25±	
52–55	153	12—5	-----	35°–20°	See "Remarks."
56	178	4.5	-----	—15	
57	223	5.5	-----	18	See "Remarks."
58–59	256±	5.0—3.5	-----	—20	See "Remarks."
60	253	5	-----	17±	
61	-----	-----	-----	-----	See Prot. No. 16.
62	320	6	-----	-----	Concentric arches. (See "Remarks.")
Coronal Streamers.					
(α)	254	-----	+56	-----	Remarkable for its great inclination.
(β)	268	-----	+28		
(γ)	5	-----	+23		
(δ)	48	-----	0	-----	Heavy; a boundary.
(ε)	42	-----	+19		
(ς)	86	-----	—18	-----	Portion of an arch.
(η)	87	-----	— 2	-----	One of several parallel streamers.
(θ)	92	-----	0		
(ϰ)	104	-----	+10±	-----	A large number of streamers involved.
(λ)	113	-----	+10±	-----	A region of well-defined streamers, visible to the very edge of the moon.
(μ)	121	-----	+10±	-----	
(ν)	190	-----	—23	-----	Band of parallel streamers covering 25°.
(ξ)	224	-----	+ 2	-----	Runs to the comet.
(π)	256	-----	—32	-----	One of many covering 20° of arc.
(ρ)	296	-----	±	-----	A boundary made of many streamers.
(σ)	356	-----	0	-----	In great wing.
(τ)	1	-----	-----	-----	In great wing; outer boundary.

The approximate positions of the axes of the main wings with reference to the pole of the sun are as follows:

Wing.	Angular Distance from Sun's Pole.
1	46°—121°
2	136
3	171
4	196
5	216—311
6	351
7	16

Between the several wings are the so-called "gaps." The method of formation of these wings and gaps will be considered later on in this paper.

As already mentioned, a rather striking feature of the outer corona, as observed at Mina Bronces, is the object which—with the aid of the English photographs—I have since shown to be a comet. Its form and position are indicated on the diagram (Plate IX), and also on Fig. 4, Plate I, remembering that the photograph, being a negative print, is *reversed.* In Print I of the same plate the tail of the comet can be traced to a distance of about six solar diameters from the sun on the less heavily printed illustrations; the head in Print I is lost in the general coronal illumination. In this position the object is wanting on the English photographs, but at greater distances from the sun the same form, only very much fainter, is shown on the positive copies sent to the Lick Observatory.

I have measured these plates, but as I am not yet in possession of the accurate location of the English eclipse stations, nor of the exact times of exposure of their photographic plates, the measured coördinates may be in error by as much as two or three minutes of arc, when referred to the true position of the *sun's* center.

To orient the English photographs the sharply defined boundary, which has been called $\varkappa$ (see diagram Plate IX), was taken as a starting point for all the English plates. The scale of each photograph was separately determined by measuring the diameter of the *moon's* image on each plate.

The evidence given by the positive copies of the negatives seems to prove that the comet was growing rapidly fainter with increasing distance from the sun; for on the African plates the comet is *very faint*, while on the Lick Observatory negatives it forms a fairly conspicuous feature of the corona. These considerations render it almost certain that the object was actually within the visible limits of the corona; and that the *theoretical* perihelion passage occurred only a few hours before the photographs were taken.

To detect, if possible, any personality in locating this object on the various plates, I requested Professor BARNARD to mark the several positions on the glass sides of the photographs. The measurements of his positions agree almost exactly with my own.

POSITIONS OF THE COMET OF APRIL 16, 1893.

Place.	Distance from Sun's Center.	Position-Angle.	$\triangle\alpha$	$\triangle\delta$
Mina Bronces	40′.0	199° 45′	—55ˢ.0	—37.6
Brazil	49 .4	196 30	—57 .0	—47.4
Africa	61 .8	193 30	—58 .7	—60.1

For the assumed Greenwich mean times given below the corresponding places of the sun are obtained, from which the comet's coördinates are deduced by applying the proper $\triangle\alpha$ and $\triangle\delta$ given above.

Greenwich Mean Time.	Sun's Apparent.		Comet's Apparent.	
	α	δ	α	δ
1ʰ 3ᵐ	1ʰ 39ᵐ 15ˢ.2	+10° 19′.2	1ʰ 38ᵐ 20ˢ.2	+9° 41′.6
2 16	1 39 26 .5	+10 20.3	1 38 29 .5	+9 32.9
3 38	1 39 39 .2	+10 21.5	1 38 40 .5	+9 21.4

CONCLUSIONS.

In March, 1890, I published the results of preliminary investigations based largely upon an examination of the coronas of January and December, 1889. The conclusions reached were stated as follows:

"My investigations seem to prove conclusively that the solar corona is caused by light emitted and reflected from streams of matter ejected from the sun by forces which, in general, act along lines normal to the surface of the sun; these forces are most active near the center of each sun-spot zone.

"Owing to the rotation of the sun, the streams of matter will not lie along normals, since the angular velocity of different portions of the stream grows less as the distance from the sun increases; in other words, the streams are of double curvature. Each individual particle of a stream, however, describes a portion of a conic section, which is a very elongated ellipse, so long as the initial velocity is less than 383 miles per second (assuming that the sun's atmosphere, as shown by various observations, is exceedingly rare).

"Owing to the change in the position of the observer with reference to the plane of the sun's equator (according as he is above, below, or in this plane), the perspective overlapping and interlacing of the two sets of streamers cause the observed apparent variations of the type of the corona."

In connection with this paper a series of eight photographs of a model were published, illustrating the various changes in the appearance of the corona at different seasons of our year. (See *Publications of the Astronomical Society of the Pacific*, Vol. II, page 68.)

A memoir entitled "A Mechanical Theory of the Solar Corona," which I finished in June, 1890, was soon thereafter published as a part of the "Report on the Total Eclipse of the Sun, December 21–22, 1889." In this memoir the laws governing the appearance of *normally* ejected streams of matter seen in orthographic projection were deduced; and the general appearance that would be produced by two sets of *uniformly* distributed streamers in the two sun-spot zones discussed. It was there shown graphically that these slightly curved and uniformly distributed streamers, when projected against others also slightly curved, could produce false stream-lines of great curvature. The rigorous analytical expression for the inclination of these false lines for two sets of parallel streamers was also given. A comparison was then made between the observed coronal forms and a *typical corona* having a *perfectly uniform* distribution of the streamers. In the typical corona false polar rays are produced.

At the time I was strongly of the opinion that nearly all of the observed polar rays were produced in the same way as in the case of the model. Certain further investigations, however, have considerably modified this view, and have led to the conclusion that while many of the apparent stream-lines are false streams, produced after the manner already spoken of, the polar rays are in the main real streams of ejected matter arranged along elliptical arcs having the sun in one focus.

In all my previous theoretical results the initial direction of motion was taken as normal to the surface of the sun, and a parabolic velocity assumed. Taken in connection with the detail given on the 18 x 22 inch plates of the 1893 eclipse, I have again gone over the various photographs of other eclipses, and find that with an initial inclination of only a few degrees to the normal and an elliptical velocity of motion *all true stream-lines* can be made to coincide with *elliptical arcs having one focus at the sun's center; the origin of the streams being, in the main, confined to the spot-zone regions.*

Immediately after returning from the 1893 eclipse expedition I published a "Preliminary Note on the Corona of April 16, 1893," together with the full-size, but poorly reproduced, copy of one of the large photographs (see *Astronomy and Astro-Physics* for 1893, page 730), shown in Plate VII. The following are some extracts from this paper:

"As bearing directly upon the theory of the corona, the photographs taken with five different instruments at the same station (Mina Bronces) show—

"First—That apparently the matter composing the prominences and protuberances visible during this eclipse was in orbital motion. In the prominences the matter is distributed with varying density along elliptical arcs symmetrical with reference to the sun; in many cases these arcs seem to be partially discontinuous; they vary all the way from a normal line to a nearly tangential curve, and attain a maximum altitude of about 80,000 miles.

"The protuberances visible during this eclipse are shown to be made up of a large number of bright elliptical streams of matter which intersect each other, in projection, at all angles. These streams are so numerous that on the smaller-scale photographs this network of lines has the appearance of a continuous surface. (In this note I consider all photographically visible matter exterior to the sun's surface as forming part of the corona, and for convenience of illustration the higher and conspicuously individual portion of any protuberance is called a prominence; the former during this eclipse attained a mean height of 20,000 miles, while the latter as conspicuous structures rose to a maximum of four times this amount.)

"Second—All the remaining visible matter forming the sun's corona is apparently of a uniform degree of composition and much less dense than the prominences and protuberances; but, like them, the matter is arranged in the form of (continuous) curved streams of various heights, and each returning stream of the inner corona is plainly visible as a portion of an ellipse whose major axis passes through the sun's center, indicating that the matter forming these streams was ejected from the sun, and is subject to the action of the sun's gravity. The symmetrical form of these complete arcs (varying again all the way from a normal line to a nearly tangential stream) indicates that this rare matter suffers practically no resistance to motion due to an atmosphere of the sun.

"Structures, again, which on the smaller plates appear to follow no law, are, with the aid of the larger plates, shown to be due to the superposition of these elliptical streams. That these arcs are not due to halation caused by the presence of bright prominences follows from the fact that the eccentricity varies as above stated, and from the further fact that no visible change of form took place with reference to the true place of the sun during the moon's transit.

"These visible returning streams are much the most numerous on either side of the sun's equator, and attain a height of 200,000 miles or more.

"Third—The outer corona is mainly caused by the more nearly radial streams of matter wholly similar in appearance to the curved returning streams of the inner corona. The various trumpet-shaped outlines so plainly visible on the smaller, wide-angle plates are seen to be due to the superposition of individual streams, which in many cases can be traced from the moon's outline on the larger plates to a distance of several solar diameters on the smaller negatives.

"In no case* have I found the actual structure to be convex towards the sun's center, and there are only a few cases of very large streamers having apparently greatly inclined initial directions of motion,* the points of eruption being on or near the sun's limb in each case.

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* The comet's outline excepted.

"The general form of the outer corona is in general agreement with the prediction for a nearly maximum inclination of the sun's north pole to the line of sight, although the axis of the inner corona cannot be accurately determined, owing to the condensed state of the projections in the polar regions. Marked extensions (nearly radial) projecting far beyond the usual elliptical outline are found in various quadrants, especially so in the north polar regions. I wish to call particular attention to a curious structure near the middle of the third quadrant; the head of this comet-like object is about four fifths of a solar diameter from the sun's surface; it is visible on all my negatives of the outer corona.

"On the DALLMEYER negatives of the outer corona the Zodiacal Light shows faintly to a distance of about eight solar diameters from the sun.

"In the 'Mechanical Theory' certain results are deduced for a typical corona produced by streamers uniformly distributed in the spot-zone. Now, it is evident that this ideal or perfect form will be the exceptional case, and for the same reason that visible solar disturbances in the two spot-zones differ not only from each other, but the study of the sun's visible surface tells us that the eruptions are not as a rule distributed with exact uniformity in longitude.

"The form resulting from an irregular distribution of the streamers can be constructed, provided the longitudes (and latitudes) of the various points of eruption and the distance from the origin are unknown.

"As the observer will in general have a less latitude than a given stream, it follows that the normally ejected outgoing matter between the earth and the sun will in projection curve away from the equator on the west side of the sun, and on the east side the curvature will be towards the sun's equator, for the reason that the outgoing streams in both the northern and southern hemispheres will be on the east side of the normals. Just the opposite condition of things will exist for the outgoing streams on the farther side of the sun. (See L. O. Report on the Eclipse of December, 1889, Plate VIII.) For the incoming streams the inclination is reversed. The resulting form of the corona in any particular quadrant will depend upon the relative amount of ejected matter in the nearer and farther hemispheres of the sun's surroundings projected in that quadrant.

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* See page 98.

"A streamer is evidently made up of a number of nearly parallel streams of matter having presumably many streams with divergent directions of motion. At great distances from the origin such a streamer projected nearly in the direction of the sun will during an eclipse appear to radiate from a considerable arc of the moon's limb, the amount and direction of the inclination being governed by the conditions above indicated.

"A considerable interval between two such sets of streamers would result in 'gaps' or 'rifts' in the corona. When such eruptions actually take place on the sun's limb those streamers which have greatly inclined initial direction of motion may evidently also become visible."

It is evident that if the "Mechanical Theory" is true the following problem should be capable of solution, viz.: Having given the structural form of the corona, to determine the location of the disturbed areas, on the sun's surface, at which the coronal matter is ejected.

With the aid of the eight negatives taken with the 40-foot telescope the diagram given in Plate IX, showing the more conspicuous coronal features, was first traced upon glass after the manner already described. The principal lines were then continued backward along elliptical arcs having the sun in one focus. I found that for the main features practically the whole corona could be accounted for by six eruption areas on the visible hemisphere of the sun, and that these areas were located within the spot-zones with such definiteness that the direction of inclination of the solar equator to the line of sight was apparently made evident. A brief study of the diagram, Plate IV, will show that these centers of disturbance, represented by the areas marked U, V, W, X, Y, and Z, cannot be shifted at will, nor does it appear necessary to introduce others to account for the main features.

Beginning with the area T, located near the sun's west limb, we have practically the whole length of the streamers, from the base up, exterior to the sun's outline; consequently the ones very much inclined to the normal, like α and its companions, will be prominent, which is not necessarily the case for other positions where the base and lower portions are projected against the sun (behind the moon). The crossing of the streamers from the small area Z accounts partly for the apparent bunching up in that position-angle.

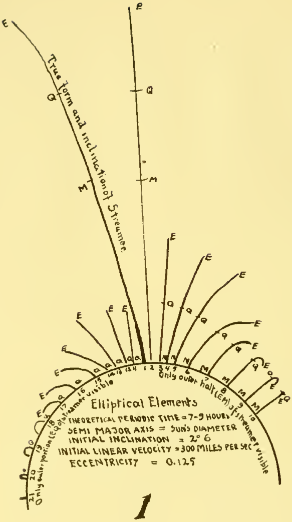
The remarkable set of well-defined streamers at the sun's west limb all converge to the area V; these streamers are reinforced by others coming from T. The two eruptions combined apparently produce the greater part of the north polar wing, the outer and eastern boundaries of which are mainly caused by the streamers from the disturbed area U, which is also the origin of the streamer γ and its nearly parallel neighbors. The area W is the source of the principal streamers which radiate from the sun's east limb. The area X also furnishes streams for the east equatorial wing, and is the center from which radiate the streams leaving the moon's outline in that position-angle.

An explanation of why and how the "wings"—and consequently the "gaps" also—are formed will now be considered, using the actual stream-lines of the corona of April 16, 1893, as a graphical illustration:

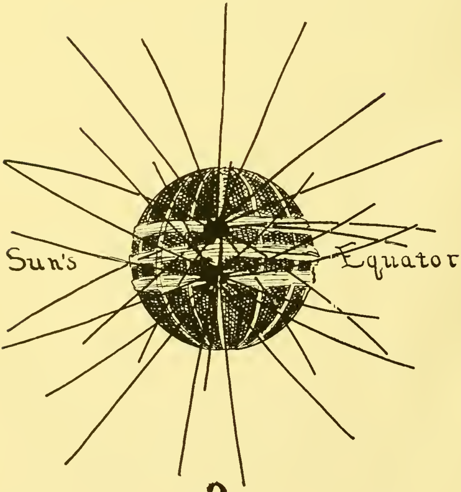
Number of Wing.	How Caused.
(1) East Equatorial Extension.	Produced mainly by streamers from W and X.
(2) East Equatorial Extension.	Produced mainly by streamers from W and V.
(3) East Equatorial Extension.	Produced mainly by streamers from T and W.
(4) East Equatorial Extension.	Produced mainly by streamers from V and T.
(5) West Equatorial Extension.	Produced mainly by streamers from T, U, V, and Z.
(6) West Equatorial Extension.	Produced mainly by streamers from U and X.
(7) West Equatorial Extension.	Produced mainly by streamers from U, X, and W.

As the space between any two wings contains less coronal matter the diminution in brightness from this cause will result in apparent gaps.

Referring now to the diagram, Plate IX, it should be said that the areas U, V, W, X, Y, Z were located entirely by means of the coronal lines shown in the diagram, without any previous knowledge of the surface conditions existing on the sun during the eclipse.


True form and inclination of Streamer.
E
Q
M
1 2 3 4 5 6 7 8 9 10
14 13 12 11
15 16 17 18 19 20 21
Only outer half (EM) of streamer visible
Only outer portion (EQ) of streamer visible
Elliptical Elements
THEORETICAL PERIODIC TIME = 7-9 HOURS
SEMI MAJOR AXIS = SUN'S DIAMETER
INITIAL INCLINATION = 2° 6
INITIAL LINEAR VELOCITY = 300 MILES PER SEC
ECCENTRICITY = 0.125

1



2

Plate X. Photograph and Drawing of a Model.

If now this rather odd arrangement of disturbed areas (theoretical) is compared with the photographic results obtained by Professor HALE* at Chicago on the day of the eclipse, an agreement between the observed and theoretical disturbed areas will at once be recognized; the coincidence seems too close to be ascribed to mere chance.

By actual trial it will be found that these areas cannot be shifted without destroying the conditions that the sun's center must coincide with one focus of the elliptical arc described by the streamer issuing from a given area.

The diagrams and discussions given in the paper entitled "A Mechanical Theory of the Solar Corona" refer in the main to streamers having a parabolic velocity and an initial normal direction of motion. We will now briefly consider some of the forms produced, in projection, by streamers slightly inclined to the normal and having a less than parabolic velocity.

To obtain a faithful representation of such a streamer, seen in projection, certain elements, similar to those which some of the streams of the 1893 corona evidently possessed, were assumed, and the true orbit drawn on a large scale, with the sun's center at one of the foci. The theoretical elements assumed are—

Semi-major axis = Sun's diameter.
Initial inclination = 2°.6.

From these two assumed constants of the orbit the following additional elements are obtained:

Theoretical periodic time = 7.9 hours.
Initial linear velocity = 300 miles per second.
Eccentricity = 0.125.

A stiff wire rod was now bent, so as to have the same curvature as the portion of the ellipse corresponding to the outgoing matter, and inserted in a large spherical ball in such a way that when the plane of the rod passed through the center of the ball the rod's inclination at the surface was 2°.6.

The projections for different positions of the same streamer, 1 M Q E, are shown in Plate X, Fig. 1, and need no further explanation here, except to state that all the forms shown are projections of only that portion of the stream represented by the curved line marked "True form and inclination of streamer." At the points of the rod marked Q and M small knots were made, to indicate the positions where the points were respectively tangent to the ball in projection.

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* *Astronomy and Astro-Physics* for 1893, page 450.

From this diagram it is evident that a slightly inclined *outgoing* streamer having a velocity sufficiently great to carry the matter one or more diameters from the sun's surface may, in projection, appear: first, to coincide with a normal; second, to have, in its actual outward course, every possible apparent inclination to a normal.

Attention is also called to the fact that, in projection, the greatest curvatures will, in general, be found near the sun's outline, and that the actual loss in brilliancy due to the orbital distance from the sun is in part made good by the resulting apparent increase in density due to the foreshortening.

The phenomena presented by a fountain-like eruption (in either sun-spot zone) of streamers nearly coinciding with the normal will, in projection, vary with the angle which the normal makes with the line of sight. If the eruption is on the central meridian in, say, the north spot-zone, a more or less symmetrical arrangement of the stream-lines with reference to the sun's north pole will be apparent.

If the main eruption is to one side of the central meridian, the apparent pole of the corona will be shifted to the same side of the sun's pole.

In general, the observer will be in less heliocentric latitude than the base of a given stream, consequently those individual streamers—of say, an eruption on the central meridian—which have the greatest inclination *towards* the earth will ordinarily be invisible, as the brighter parts will be projected against the sun's disk (behind the moon); when visible, however, at the moon's outline, and in the same hemisphere as the eruption, the inclination of the stream-lines will, in projection, become greater and greater as the angular distance from the nearer pole increases. If the display is made chiefly by those streamers of the same eruption, which have component inclinations *away* from the earth, the form in projection will be of the same general character, but the curvature away from the nearer pole will not be so great.

Streamers on the central meridian issuing from one hemisphere, and projected at the moon's outline in the opposite hemisphere, will always curve away from the equator.

When the eruption is not on the central meridian the curvatures may be either towards or away from the nearer pole.

To illustrate graphically some of the infinite variety of forms which these eruptions on the solar surface can produce, we will take the case of two eruptions on the central meridian, one being in the north, the other in the south spot-zone. Fig. 2, Plate X, is a photograph of an actual model. Each eruption is represented by sixteen wire rods having, with the exception of the eccentricity, the same elements of curvature as those given in Fig. 1 of the same plate.

As the observer is supposed to be nearly in the plane of the sun's equator, and the disturbed areas in about 15° latitude, I have not included rods which, on account of their small inclination, would only just be visible beyond the outlines of the globe (the forms for such cases are given in Fig. 1). Many rods would produce too large a surface area representing the disturbed locality.

The rods were bent to two different ellipses. In each zone eight have an eccentricity of 0.3, and for the other eight of each set the eccentricity is 0.5, corresponding, roughly, to initial inclinations of 20° and 30°, respectively, the semi-major axis being equal to the sun's diameter. All the rods were cut to the same linear length as in Fig. 1, consequently only outgrowing matter is represented.

So long as the internal forces in longitude are not greatly different it is evident that the eruptions on the central meridian will have the controlling influence in shaping the form of the structure at the poles; for these streamers will overlie (viz., be nearer to the observer) and be seen at less distance from the origin than streamers coming from other longitudes and projected at the poles at great distances from the origin.

Referring now to Fig. 2, Plate X, it will be noticed that even with only two eruptions on the central meridian the method of formation of the great equatorial wings is clearly shown. In *projection* the number of eruptions will, as a rule, increase as the distance from the central meridian increases. The equatorial extent will therefore, in general, be greater than the polar. It will also be noticed that in every case where the inclination is towards the nearer pole, only the outer and consequently the faintest portion of the streamer would be projected, so that under ordinary conditions it would be wholly lost in the brighter streamers inclining away from the nearer pole.

If we call the line marked "Sun's Equator" the *polar* axis of the sun, it will be noticed that eruptions in different longitudes may produce wings in the polar regions, and that the inclinations may be both towards and away from the nearer pole.

The effects produced by changes in the observer's position with reference to the plane of the sun's equator have been considered in a former paper,* and the same general effects will result from inclined streamers.

These considerations render it quite probable that streamers from the meridian of the farther hemisphere are seldom bright enough to show as conspicuous objects at the poles of the sun, the observed inclinations being now very satisfactorily shown to be due to streamers having inclined initial directions of motion. In general, the structural outlines of the corona are due, almost wholly, to matter ejected from the nearer hemisphere of the sun; that projected at the poles coming, as a rule, from near the central meridian, while the matter forming the equatorial extensions comes more from those areas which are projected nearer to the borders of the disk.

During the April, 1893, eclipse there were no large eruptive areas in the northern zone between the one marked U, in Plate IX, and the western border of the sun's disk, consequently the streamers from the great eruption at V and those from T were rendered comparatively conspicuous, although the former were at considerable distances from the origin, as is also shown by the fact that the least dense part of the corona is where these very streamers cover the greatest arc of the moon's outline.

The evidence here offered that only the higher portions of the band of well-defined streamers between $p = 245^\circ$ and $p = 280^\circ$ are seen in projection, is as follows:

First—If these streamers projected at the moon's outline are issuing from points on the sun's surface near the *limb*, then many centers of eruption must be assumed, each one sending out only a single stream which is practically parallel to its adjacent neighbors, an hypothesis wholly contrary to the observed arrangements at other parts of the disk. The electrical theory might in this case account for the *regularity* of a *portion* of this family of streamers, but even for this limited number the direction of inclination is wholly contrary to the requirements demanded by such a polarized sphere.

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* A Mechanical Theory of the Solar Corona.

Second—At great distances from the origin, on the other hand, just such a spreading of streamers issuing from the same area will result. The more inclined ones, while having the same initial velocity of motion, will not reach the same altitudes as the less inclined ones. Consequently the latter will possess greater apparent regularity of structure than would be the case near the bases of the streams, where the more inclined ones would form arches and the less inclined ones be condensed into a bunch of streams occupying a very small arc of the moon's outline.

From a fundamental law of mechanics, deduced from a consideration of the free motion of a particle under the action of a central gravitating force, it follows that the semi-major axes of all the orbits described by different particles or streams of particles issuing from the sun with the same velocity will be equal to each other, *whatever* the initial inclination may be. Now, if the semi-major axis is only as great as the sun's diameter, a streamer actually issuing from near the sun's limb and moving in a plane nearly perpendicular to the line of sight, will deviate but slightly from a straight line for a considerable distance from the moon's outline, even when the initial inclination is as great as 60°.

As an illustrative example, I have taken the most inclined of the conspicuous streamers marked α, on Plate IX. Near the moon's outline the deviation from a straight line is but slight, although the inclination is about 56°.

I find, however, the whole visible portion of the stream coincides with the arc of an ellipse whose focus is at the sun's center, and whose semi-major axis in projection is but little greater than the sun's diameter.

A probable orbit corresponding to one of the less inclined streamers (β) is also shown in Plate IX.

One of the features of the outer corona which early attracted my attention during the examination of the Lick Observatory eclipse negatives is a very peculiar arrangement of coronal matter in the third quadrant. The appearance is so strikingly similar to that which comets near the sun present that only the lack of orbital motion in the object (which during an interval of less than three minutes was of course inappreciable on the plates) prevented me from announcing it as a comet. Immediately after my return from the expedition particular attention was called to this structure. It was more than a year after the eclipse before I was enabled to announce* definitely the cometary character of the object, which I then also at once found on the plates of the English expeditions to Brazil and Africa, and on the Harvard College Observatory plates exposed in Chile.

Views which I had long been inclined to favor were so strongly supported by the evidence of the eclipse plates, as shown in the suggestive arrangement of the cometary lines with reference to those of the streamers, that a "Preliminary Note on a Mechanical Theory of Comets" was published in the *Astronomical Journal*, No. 306.

Direct observations of the sun's surroundings demonstrate the presence of masses of matter ejected from the sun with very great velocity. That this matter is not of a uniform density seems to be plainly proved by the evidence of the eclipse photographs. The prominences, for instance, rise to certain limiting heights corresponding to certain definite initial velocities of motion. The coronal streams, on the other hand, rise to indefinite heights, and must therefore have, in general, much greater initial velocities.

Any given eruption doubtless gives rise to both prominences and streams. As the ejective force may be assumed common to both, the mass of a given volume of coronal matter must be less than that of a prominence, and this evidence seems to be given by all eclipse photographs showing both forms.

If now we assume the mean density of a coronal stream to be even as great as one seventh of that of an accompanying prominence, the same explosive force which during the last eclipse sent prominence matter to a height of 80,000 miles will send coronal matter forming the streams to an infinite distance. Each eruption is sending out minute particles of matter with great velocity, and the solid angle of the ellipsoidal surface inclosing them all may evidently be quite large. Aside from gravitational influences these particles suffer no resistance to motion in space, except where they come into contact with other particles of matter moving *in vacuo.*

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* See *Astronomical Journal*, No. 318.

It was my intention to embody in this report a rather exhaustive discussion of the available data bearing upon comets, as related to the corona, but the amount of material to be gone over is so great that it has been deemed best not to delay the eclipse report on this account. It is hoped that more or less complete discussion relating solely to comets may later on be published.

For the present the following remarks will indicate the nature of some of the more probable conclusions reached.

First—A comet is a large meteor whose composition is of such a nature that certain or all of its constituents are evaporated at comparatively low temperatures. The atmosphere thus formed will, on account of the small mass, always be most dense on the side where the evaporation is most rapid. When the evaporation ceases, this atmosphere will tend to arrange itself symmetrically with reference to the nucleus, so long as no other material bodies come into contact with it. Tidal effects will always have a tendency to cause greater or less dissymmetry of form.

Second—An increase of temperature, brought about both by a diminishing distance from the sun and by collisions with minute material particles in space will be accompanied by a corresponding increase in the mass of the surrounding atmosphere, due both to a more rapid evaporation from the nucleus and to a temporary or permanent capture of the colliding particles.

Third—The attraction which the nucleus exerts upon its atmosphere is so extremely small that each of the more distant particles of this atmosphere can be considered as describing an independent orbit, the mean of the separate orbits thus described practically coinciding with that of the nucleus. When the meteorite is very near the sun the evaporation on the sun side of the nucleus will be very rapid, which, combined with tidal influences, may result in the rupture of the nucleus.

Fourth—The tail of a comet (theoretical) is produced both by the visible particles of matter originally forming the comet's atmosphere, and by the previously invisible particles of a coronal stream which, moving with great velocity, finally produce by repeated impact of the successive particles almost the same motions in the visible atmosphere of the comet as would be communicated by a continuously accelerating force directed away from the sun. The actions on the particles of the stream result in a diminution of the velocity of the more advanced portions which now become visible through a consequent increase of density. A peculiarity of this mechanical accelerating force is that it becomes zero when the particle repeatedly struck by a succession of other particles finally attains the same finite velocity as the stream of striking bodies.

Fifth—As all the particles of a given coronal stream have the same velocity, the energy of the heavier sets of particles will be greater than the energy of those having less mass. Let $m_1, m_2, m_3 \ldots . m_n$ denote the masses of different particles of the stream which strike the comet's atmosphere, and let v denote the velocity, the total energy at a given instant will be

$$v^2 \Sigma m = v^2 \Sigma m_1 + v^2 \Sigma m_2 + \ldots . v^2 \Sigma m_n$$

A particle whose mass is m_1 will penetrate the atmosphere to a distance s_1 before being brought to a state of rest relatively to the nucleus. Similarly the particles whose masses are m_2, $m_3 \ldots . m_n$ will penetrate the atmosphere to the respective distances $s_2, s_3 \ldots . s_n$. The resulting strata of increased density of the comet's atmosphere will evidently be nearly concentric, the distances between any two strata f and t being $(s_f - s_t)$.

These strata of increased density will in projection be made manifest in the form of luminous, nearly concentric, arcs, whose greatest brilliancy will, in general, be near the most advanced part of each stratum, and gradually diminish in brightness as they curve away to form the comet's tail.

Sixth—The coronal matter, owing to its retardation, may grow so dense that it also becomes visible, and with the comet's atmosphere is finally driven into the tail by the repeated bombardment of unretarded following portions of the stream.

It is evident that the resulting velocity of different parts of the comet's tail will depend both upon the mass of each individual striking particle, and upon the mass of the particle struck. In general, the coronal particles which have the greatest mass will, after collision, give the greatest velocity, which (like the remaining masses) is gradually accelerated as above described, until the speed again becomes so great that no sensible illumination results from the scattered particles. The nucleus and inner portions of the atmosphere, being the most dense, block the passage of the particles so that the axis of the tail will usually have less matter than the space at some distance from the axis.

The severest test of any given theory is its ability to account for abnormal deviations from a typical form. Some of the most remarkable will be briefly considered.

Many coronal streams issue from the sun at considerable angles with the normals; in space, therefore, different streams will cross each other without sensibly interfering with each other's motions. The atmosphere of a comet, however, when placed at such a crossing, will evidently produce as many different tails to the nucleus as there are crossing streams; the angles between the tails being a function of the velocities of motion and the inclinations of the streams.

There are several cases on record of comets having a tail, in addition to the usual appendage, turned *towards* the sun. I have examined every case known to me, and find that invariably at the time this phenomenon was observed the comet was *receding* from the sun with great velocity. *A coronal stream, having a less velocity than that of the receding comet, will under these circumstances cause just such a phenomenon the moment the comet enters the stream.* Evidently the main tail will in no way be sensibly affected, since the tenuity of the two coronal streams (one moving with greater velocity than the comet, and the other with less velocity) is so great that no sensible interdisturbance takes place.

Owing to the orbital motion of the comet, different tails will result when the velocities in the tail (as a whole) at a given distance from the nucleus are largely and abruptly different. The curvature will be greatest for the tail which has the least velocity. If a gradual variation in the velocity results, a gradually broadening tail (in general more curved in projection on one side than on the other) will result.

Rapid variations in the form and brightness of the comet will result from the lateral orbital motion of the comet with respect to the stream, often passing from one stream into another. A comet loses its tail if for a considerable time it passes from a stream of greater (or less) velocity, into space sensibly devoid of coronal matter, or into a stream having the same velocity and direction of motion.

When the velocity of the particles in the more distant portions of the tail is much less than that of the streams the deviation of the axis of the tail from the produced radius vector of the nucleus will become so great that fresh and unretarded streams can plow their way through (across) these more distant parts of the tail, which may result in a visible phenomenon of a striated or columnar structure (as actually observed by BOND and others, in DONATI's comet); the axis of each column being roughly parallel to the direction of these coronal streams. Sudden and sharply abrupt changes in the direction of a comet's tail at great distances from the nucleus will be caused whenever the tail enters another coronal stream whose direction of motion is considerably inclined to the stream passing through the comet's nucleus.

A natural consequence of such motions of coronal matter is to deprive all bodies, of very small mass, of any non-growing atmosphere they may have; and also to fix the limit of distance beyond which a body of great mass cannot retain its atmosphere. In this connection I would again call attention to the fact that the phenomenon of the "Gegenschein" can be quite satisfactorily explained on this hypothesis, and that the results following from the capture of coronal particles by our own atmosphere lead to a plausible explanation of the aurora. (See *December, 1889, Eclipse Report, Lick Observatory.*)

A comet differs from a planet chiefly in three ways:

First—The great extent of its atmosphere of individual particles.

Second—The small density.

Third—The non-symmetrical arrangement of the particles with reference to a central nucleus.

All of these differences can be wholly ascribed to a lack of attractive power of the comet's nucleus. It is practically certain that if the mass of the nucleus were as great as any of the major planets all the cometary characteristic appearances would be wanting.

This being the case, it follows that if a given nucleus exercises only a very slight attractive force on particles in its immediate neighborhood, any extraneous rare matter moving through space with great velocity may by direct impact cause immediate displacements of the cometary particles, accompanied by a retardation of the rare matter.

When we inquire from whence this previously invisible rare matter comes we are forced to confess that the evidence obtained through observations of the sun's immediate surroundings renders it very probable that coronal matter is carried to indefinite distances from the sun on all sides, and that this matter is most dense near the plane of the sun's equator.

Any obstruction to the free motion of a coronal stream would tend to lessen its velocity and consequently cause an increase in its light-reflecting power, due to the resulting increase in the density.

Viewed in this light all comets having tails indicate the presence of coronal streams.

A planet, being a body with comparatively large mass, either captures such coronal particles, or it is situated at the focus of every orbit described by the various particles. The instantaneous elements of these various orbits will always be widely different. For these reasons planets can never be accompanied by streams of matter directed away from the sun.

The objections to be raised against the electrical theory of comets and the corona are, as they seem to the writer, of such a very serious nature that with our present knowledge of the condition of space exterior to the earth all deductions relating to the electrical conditions in this space must be considered to be of a purely speculative character.

We have no direct evidence that the sun is an electrified body. We have direct evidence that the sun is continually ejecting enormous quantities of material particles of matter with very great velocity.

The matter of the great and wholly improbable variations of solar electrical energy which would be required to account for the sudden and remarkable changes (both terrestrial and celestial) observed at great distances from the sun, has been so well commented upon by one of the ablest physicists of the nineteenth century, Lord KELVIN, that a few extracts from his "Presidential Address before the Royal Society" are here given.

In speaking of certain observed terrestrial phenomena so often ascribed to forces emanating from a supposed magnetic condition of the sun, Lord KELVIN says:

"It has certainly been a very tempting hypothesis, that quantities of meteoric matter suddenly falling into the sun is the cause, or one of the causes, of those disturbances to which magnetic storms on the earth are due. We may, indeed, knowing that meteorites do fall into the earth, assume without doubt that much more of them fall, in the same time, into the sun. Astronomical reasons, however, led me long ago to conclude that their quantity annually, or per century, or per thousand years, is much too small to supply the energy given out by the sun in heat and light radiated through space, and led me to adopt unqualifiedly HELMHOLTZ's theory, that work done by gravitation on the shrinking mass is the true source of the sun's heat, as given out at present, and has been so for several thousand years or several million years. * * * But now let us consider for a moment the work which must be done at the sun to produce a terrestrial storm. Take, for example, the magnetic storm of June 25, 1885, of which ADAMS gives particulars in his paper of June, 1891. (*Phil. Trans.*, p. 139, and pl. 9.) * * * The storm lasted altogether from about noon to 8 P. M. * * * Thus in this eight hours of a not very severe magnetic storm as much work must have been done by the sun in sending magnetic waves out in all directions through space as he actually does in four months of his regular heat and light. This result, it seems to me, is absolutely conclusive against the supposition that terrestrial magnetic storms are due to magnetic action of the sun; or to any kind of dynamical action taking place within the sun, or in connection with hurricanes in his atmosphere, or anywhere near the sun outside."

Lord KELVIN's remarks must be construed as referring only to such dynamical forces as would cause the sun to be the center of energy radiated in all directions, and not to the forces acting only at particular and very limited areas on the sun; for evidently only a comparatively small force would be required to send a single stream of material particles to the earth's distance from the sun.

The sudden stoppage and capture of each coronal particle by our atmosphere is, on a small scale, doubtless accompanied by magnetic phenomena similar to those observed in falling meteors, great numbers of these particles producing finite and appreciable results.

This phase of the subject has been referred to in the *Lick Observatory Eclipse Report for December, 1889*, and need not be enlarged upon here.

The unexplained cause of a periodical variation in the solar surface features has given rise to various theories ever since the discovery of this variation by SCHWABE, and the later investigations of CARRINGTON, WOLFF, SPOERER, and many others. The arrangements of the solar prominences observed in full sunshine with the spectroscope also indicate that, as in the case of the solar spots, in certain areas on the sun's surface, the resistance to internal pressure, or the areas of greatest surface strength, seem to lie in movable zones parallel to the equator.

From these indications I was led, in a general way, to consider certain phenomena which would seem to follow from certain assumed solar conditions. These considerations were embodied in a descriptive paper published in the April (1894) number of *Astronomy and Astro-Physics.*

To sum up the results of the study relating more particularly to the corona of April 16, 1893, the following conclusions are arrived at:

First—All visible matter exterior to the sun's surface is apparently in rapid motion, the path described corresponding to one of the conic sections. The so-called stationary prominences are probably stationary as to the general form only, the matter—which remains visible so long as the density is sufficiently great—in the same being in rapid motion. I have carefully compared the eclipse photographs taken with the 40-foot telescope on April 16, 1893, with the best spectroscopic observations accessible (both visual and photographic) taken of the uneclipsed sun on the same day, and the result briefly stated is that while the coarser features of the sun's surroundings are shown in spectroscopic observations of the uneclipsed sun, *the finer and essential details are wanting.*

Second—All coronal streamers are apparently composed of matter ejected from the sun with great velocity; this matter moves in one of the conic sections, and has its origin mainly in the sun-spot zones. In general, when seen at the moon's outline, in projection, any given portion of a coronal stream is in reality at a great distance from the sun.

Third—A so-called wing of the corona is apparently produced by the overlapping in projection of many streams of matter coming from two (or more) different centers of eruption; the direction of the axis or greatest extent of the wing being in general (roughly) at right angles to the line joining the two eruptive centers. A necessary consequence resulting from the formation of wings is the formation of "gaps" in the corona; a "gap" being the less dense area between two adjacent wings.

As to the degree of confidence which may be given to the conclusions embodied in this "Report," it should be stated for the benefit of the general reader that even a most casual study of the solar literature of the last few years will indicate that astronomers in general incline to the belief that electrical and magnetic forces in the sun's immediate neighborhood determine the arrangement of the finely divided matter near the sun. My own investigations seem to show that, so far as the eclipse of April, 1893, is concerned, there is no evidence to indicate that either electricity or magnetism has anything to do with the arrangement of coronal matter in the sun's neighborhood. A reëxamination of the photographs of other eclipses of which the Observatory has copies leads to the same conclusion, viz.: there is no necessity of introducing either electrical or magnetic forces to account for any of the coronal forms, as each true stream-line is found to lie on the arc of a conic section having the sun at the focus. The abnormally curved stream-lines, usually forming wing boundaries on the smaller-scale photographs of the present eclipse, are on the larger negatives shown to be due to the overlapping of different nearly osculating streamers; the individual members, however, can be made to coincide with the arc of a gravitational conic section. It is almost certain that the abnormal outlines recorded for other eclipses are produced in a similar manner.

WORKS ISSUED BY THE LICK OBSERVATORY.

⁂ It is intended to issue, at irregular intervals, two series of works, the first in quarto, to be known as *Publications* of the Lick Observatory; the second, in octavo, to be known as *Contributions* from the Lick Observatory. Occasional pamphlets such as No. 2 below, may not be included in either series. At the end of every book, a list of all the works issued will be given, for the convenience of librarians and others.

For the sake of uniformity, Nos. 3 and 4 below will be counted as *Contributions* Nos. 1 and 2.

1. *Publications* of the Lick Observatory of the University of California. Prepared under the direction of the Lick Trustees, by EDWARD S. HOLDEN, Volume I, 1887. Sacramento, 1887. 4to. [Containing a brief history of the Observatory, with descriptions of the buildings and instruments; observations of double stars by S. W. BURNHAM, 1879, of the transit of *Mercury*, 1881, by Messrs. FLOYD, HOLDEN, and BURNHAM, of the transit of *Venus*, 1882, by D. P. TODD; meteorological observations, by T. E. FRASER, 1880–85; and Reduction Tables for Mount Hamilton, by G. C. COMSTOCK.] [Out of print.]
2. Suggestions for observing the Total Eclipse of the Sun on January 1, 1889, by EDWARD S. HOLDEN. Printed by authority of the Regents of the University of California. Sacramento, 1888. 8vo. [Out of print.]
3. *Contributions* from the Lick Observatory, No. 1. Reports on the Observations of the Total Eclipse of the Sun of January 1, 1889, published by the Lick Observatory. Printed by authority of the Regents of the University of California. Sacramento, 1889. 8vo. [Out of print.]
4. *Contributions* from the Lick Observatory, No. 2. Reports on the Observations of the Total Eclipse of the Sun, December 21–22, 1889, and of the Total Eclipse of the Moon, July 22, 1888, to which is added a Catalogue of the Library, published by the Lick Observatory. Printed by authority of the Regents of the University of California. Sacramento, 1891. 8vo. [Out of print.]
5. *Contributions* from the Lick Observatory, No. 3. Terrestrial Atmospheric Absorption of the Photographic Rays of Light, by J. M. SCHAEBERLE, Astronomer in the Lick Observatory. Printed by authority of the Regents of the University of California. Sacramento, 1893. 8vo.
6. *Publications* of the Lick Observatory of the University of California. Printed by authority of the Regents of the University. Volume II, 1894. Sacramento, 1894. 4to. [Containing double-star observations made with the 36-inch and 12-inch refractors of the Lick Observatory, from August, 1888, to June, 1892, by S. W. BURNHAM.]
7. *Publications* of the Lick Observatory of the University of California. Printed by authority of the Regents of the University. Volume III, 1894. Sacramento, 1894. 4to. [Containing drawings and photographs of the Moon, by Prof. LADISLAS WEINEK, reproduced in heliogravure, etc., with an introduction by EDWARD S. HOLDEN; investigation of prisms of optical glass, by Prof. C. S. HASTINGS; investigation of the glass scale of the Lick Observatory Measuring Engine, by Mr. O. H. TITTMAN; spectroscopic observations of Nebulæ, by Prof. J. E. KEELER.] [Out of print.]
8. *Contributions* from the Lick Observatory, No. 4. Report on the Total Eclipse of the Sun, observed at Mina Bronces, Chile, on April 16, 1893, by J. M. SCHAEBERLE, Astronomer in the Lick Observatory. Printed by authority of the Regents of the University of California. Sacramento, 1895. 8vo.

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